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AN IMPLEMENTATION AND ANALYSIS OF THE ABSTRACT SYNTAX NOTATION ONE AND THE BASIC ENCODING RULES

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Digital Technology

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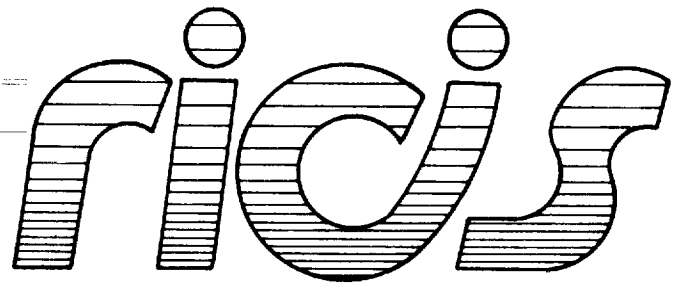

Research Institute for Computing and Information Systems
University of Houston - Clear Lake

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AN IMPLEMENTATION AND ANALYSIS OF THE ABSTRACT SYNTAX NOTATION ONE AND THE BASIC ENCODING RULES

Preface

This research was conducted under the auspices of the Research Institute for Computing and Information Systems by James D. Harvey and Alfred C. Weaver by Digital Technology. Dr. George Collins, Associate Professor of Computer Systems Design, served as RICIS technical representative for this activity.

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An Implementation and Analysis of the Abstract Syntax Notation One and the Basic Encoding Rules

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Alfred C. Weaver

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ABSTRACT

The development of computer science has produced a vast number of machine architectures, programming languages, and compiler technologies. The cross product of these three characteristics defines the spectrum of previous and present data representation methodologies. With regard to computer networks, the uniqueness of these methodologies presents an obstacle when disparate host environments are to be interconnected. Interoperability within a heterogeneous network relies upon the establishment of some sort of data representation commonality.

The International Standards Organization (ISO) is currently developing the Abstract Syntax Notation One standard (ASN.1) and the Basic Encoding Rules standard (BER) that collectively address this problem. When used within the Presentation Layer of the Open Systems Interconnection Reference Model, ASN.1 and BER provide the data representation commonality required to facilitate interoperability. This thesis presents the details of ASN.1 and BER and describes a compiler that was built to automate their use. Experiences with this compiler are also discussed which provide a quantitative analysis of the performance costs associated with the application of these standards. Ultimately, an evaluation is offered as to how well suited ASN.1 and BER are in solving the common data representation problem.

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1. Network Heterogeneity

The development of computer science has produced a vast number of disparate machine architectures, programming languages, and compiler technologies. The cross product of these three characteristics defines the spectrum of previous and present data representation methodologies. Although at one time the uniqueness of each technique provided vendors with a convenient and desirable means to monopolize their customers, the proliferation of computers and the realization of the benefits inherent to distributed processing have now obscured any of the previous advantages associated with incompatible data representations. Nevertheless, established manufacturers are unwilling to abandon their investment in their own unique data representation schemes. Thus when computer networks interconnect these heterogeneous environments, a solution to the problem of data transfer across incompatible host environments must be provided.

1.1 Architectural Issues

As a simple illustration of how hardware architecture influences this problem, consider three different techniques used to represent integer values: sign magnitude, diminished radix complement (one's complement), and radix complement (two's complement). Although most contemporary architectures now use two's complement, there are some architectures still in use that do not.[1] Consequently, if integer data were to be exchanged between a one's complement

1. The CDC 6600 is a one's complement architecture.

machine and a two's complement machine, each computer would have a different interpretation of the "same" negative values. For example, the two byte, two's complement representation of the value -2, depicted in Figure 1, would be interpreted as -1 by a one's complement machine.

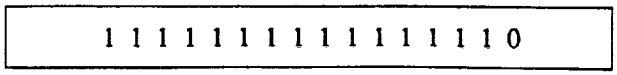


Figure 1. Two's Complement Representation of Negative Two

As a further exacerbation of this problem, the relative storage size that each computer allocates for an integer value may also differ.

Other data types also suffer from this representation disparity; the most obvious is floating point numbers. Almost all of the microprocessors and arithmetic co-processors that are currently being manufactured now use the IEEE floating point standard to represent real numbers. In its single-precision form, the radix of the exponent is two, the radix of the base is two, the radix of the fractional mantissa is two, the number of fractional mantissa digits is twenty-three, and the number of exponent digits is eight. The format of a single-precision IEEE floating point number is given in Figure 2.

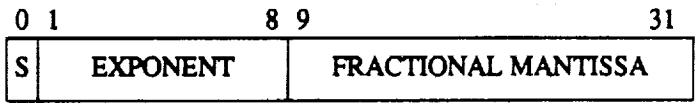


Figure 2. IEEE Floating Point Format

The rules that dictate the construction and interpretation of an IEEE floating point value are as follows:[2]

2. Let s = sign, e = exponent, f = fractional mantissa;

1. If the exponent value is 255 and the fractional mantissa is a nonzero value, then the value represented is not a number.

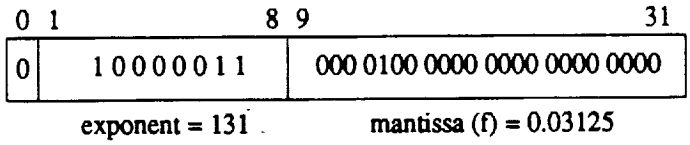
2. If the exponent value is 255 and the fractional mantissa is zero, then the value represented is positive infinity if the sign bit is zero and negative infinity otherwise.

3. If the exponent value falls within the range 1..254, then the value represented is characterized by the expression: $(-1)^s\ 2^{(e-127)}\ (1.f)$.

4. If the exponent value is zero and the fractional mantissa is nonzero, then the value represented is characterized by the expression: $(-1)^s\ 2^{-126}\ (0.f)$.

5. If the exponent value is zero and the fractional mantissa is also zero, then the value represented is zero.

As an example of an IEEE floating point value, rule number three indicates that the numeric value 16.5 would be represented by the 41840000_{16}. This representation is depicted in Figure 3.



$(-1)^0\ 2^{(131-127)}\ (1.03125) = 16.5$ (*rule* 3)

Figure 3. IEEE Representation of 16.5

In comparison, IBM architectures employ a convention of real number representation which is entirely different from that of the IEEE standard. While both methods use thirty-two bits in their single-precision form, the exponent of the IBM standard occupies only seven bits while the mantissa occupies twenty-four. Moreover, the radix of the exponent is sixteen rather than two and the exponent is also biased by sixty-four (excess-64 notation). The format of an IBM single-precision floating value is given in Figure 4.

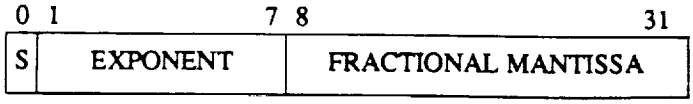
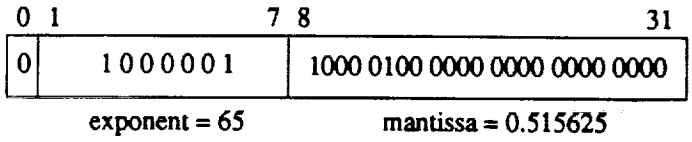


Figure 4. IBM Floating Point Format

The obvious consequence of these differences in floating point representations is the inability for one machine to correctly interpret the data representation of the other. If a machine that uses the IEEE standard were to send its single-precision representation of the value 16.5 (i.e. 41840000_{16}) to an IBM mainframe, the IBM computer would interpret this value as 8.25 rather than 16.5. This is illustrated in Figure 5.



$$(-1)^0\ 16^{(65-64)}\ (0.515625) = 8.25$$

Figure 5. The IBM Interpretation

To complicate the architectural issues even further, characteristics such as word alignment, byte ordering, and addressability may also present problems. Moreover, the influence of hardware architecture extends beyond just that of the CPU. This is evident when one considers the difference between the ASCII and EBCDIC character sets. Certainly the architecture of peripherals also bears significance. The interaction and interdependencies that exist between all of these characteristics suggest that the influence of hardware architecture on the problem of disparate data representations is complex.

1.2 Languages and Compilers

The differences in conditional expression evaluation that occur within the C and Ada programming languages demonstrate the manner in which programming languages can contribute

to this problem. In all C implementations a conditional expression is **true** if it evaluates to any non-zero value; it is consequently **false** if it evaluates to zero precisely. Although the C programming language does not explicitly provide a boolean type, most C programmers use an integer data type to represent these kinds of values. In Ada, however, a boolean type *is* predefined as an enumerated type in package STANDARD. By virtue of its enumerated form, the only requirement relating to the representation of its values is that the representation of **false** be numerically less than the representation of **true**. Thus, each individual Ada compiler determines the exact nature of how boolean values are represented. Since Ada treats conditional expressions as boolean values, the evaluation of such expressions may clearly vary. In this respect, if the same application program were to be implemented in two different programming languages, it is feasible for two values that are intended to represent the "same" condition to be different. In fact, it is more precise to attribute this phenomenon to the differences between compiler implementations than to the difference between programming language definitions.[3] Consequently, applications written in the "same" programming language may experience miscommunication.

1.3 Solving the Problem

With regard to network heterogeneity, the disparate data representation problem is clear. Since different host environments possess different methods of representing data, the interoperability of these machines can not be achieved solely by the establishment of a reliable connection. At some point during the communication, a transformation to and from each host

3. MicroSoft C compilers treat character values as signed quantities by default. Consequently, all character values are sign extended during type conversions. Lattice C compilers, however, consider all character values to be unsigned by default and do not sign extend.

machine's native representation must be performed. This function could be carried out in one of two ways: either (1) each host environment must be cognizant of the representation characteristics of each other host environment with which it wishes to communicate, and therefore each host must perform a potentially different transformation for every host-to-host combination, or (2) a common method of data representation must be established whereupon each host would be responsible for the single transformation between this standard method and its own native representation. This latter approach, which is certainly the more desirable alternative, captures the intent of the Abstract Syntax Notation One and the associated Basic Encoding Rules.

2. The OSI Model

As a solution to the problem of disparate data representations, the International Organization for Standardization (ISO) has developed the Abstract Syntax Notation One standard [1] (ISO 8824) and the Basic Encoding Rules standard [2] (ISO 8825). Defined in the context of network communications, the purpose of these two standards is to provide the data representation commonality required to interconnect disparate host environments. To understand how Abstract Syntax Notation One (ASN.1) and the Basic Encoding Rules (BER) provide a solution to this problem, it is necessary that one first understand the Open Systems Interconnection (OSI) model, the environment in which these two standards operate.

2.1 Layered Protocols

The design and implementation of a network is an inherently complex task. There are a wide range of problems to be solved which collectively demand expertise in many different theoretical disciplines. To offer structure to this process and thereby minimize its complexity, most networks are organized as a series of layers where each layer encapsulates a particular aspect of the problem. The relationship between these layers is hierarchical. Each layer is dependent upon the services provided by the layer directly beneath it and is, by the same token, responsible for providing a set of services to the layer directly above it. The number of layers, the names of each layer, and the functionality provided by each layer may differ from one network design to another. However, the overall objective of simplifying the problem through a hierarchy of

abstractions is universal.

Since each layer of a network implementation is responsible for providing a set of services to the layer directly above it, the exact nature of these services is reflected by the interface that exists between them. The most important requirement of this relationship is that the implementation details of how any given layer provides its services should be transparent to the layer that uses it. Hence, each layer has a different perspective of the communications problem to be solved. Put another way, each layer creates an abstraction of communication capabilities to the layers above it. These capabilities increase in sophistication as one proceeds up the stack.

During an instance of communication, each layer within an implementation carries on a conversation with the corresponding layer of another implementation. A well defined set of rules and conventions, known as a **protocol**, govern the manner in which each conversation is carried out. These pairs of communicating layers are often called **peers** or **peer protocols**. The hierarchical structure of these protocols gives rise to the term **layered protocols** or **protocol stack**. This arrangement is illustrated in Figure 6 below.

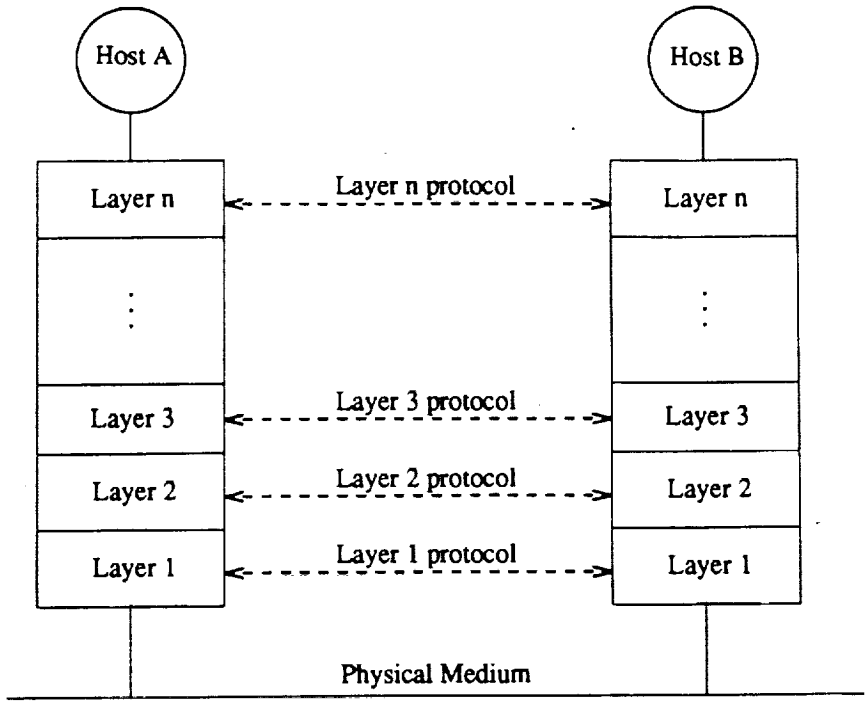


Figure 6. A Network Stack

As a conceptual model it is useful to think of a protocol stack in this way. Yet, it is important to realize that there is only one physical means of communication between the layers; this occurs over the physical medium. Consequently, only the lowest layer in each respective stack is involved in the direct transfer of data. In the case of the upper layer protocols the communication is virtual. Data flows up and down each stack as the communication between the host machines proceeds. The direction of flow indicates whether the stack is sending or receiving. Each upper layer communicates with its peer through the Protocol Data Units (PDU's) it exchanges with the layers directly above and below it.

2.2 The ISO Stack

In 1977, ISO established a subcommittee to develop a standard that would formalize the layered approach to network design. The objective of this task was to establish an architecture that would ultimately provide a context to which other network related standards could be

applied. The result was the creation of a new standard (ISO 7498) which defined the Open Systems Interconnection (OSI) reference model. The framework that OSI represents enables the consistency of all relevant communications standards to be maintained. The OSI reference model is commonly referred to as the **ISO stack**.

The seven layers of the ISO stack are depicted in Figure 7.

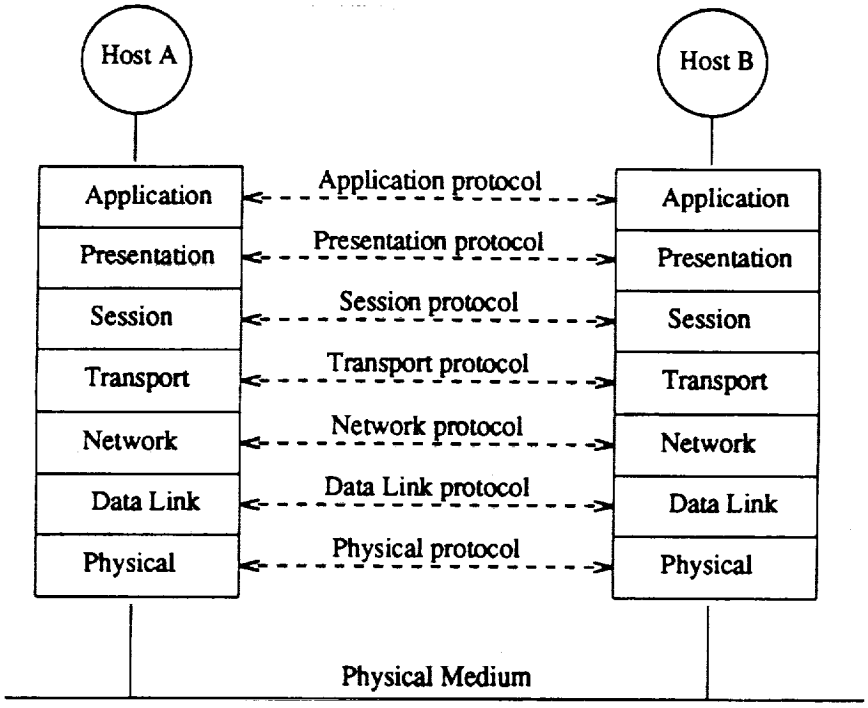


Figure 7. The ISO Stack

The functionality of each one of the seven ISO layers is as follows:

1. **Physical Layer:** It is the responsibility of the Physical Layer to facilitate the transmission of raw bits over a communication medium. As such, the Physical Layer provides the interface between the binary values and the physical signaling. Typical design issues relevant to the Physical Layer are:

    a. how the data is to be physically represented (i.e., voltage levels, lightwave characteristics, etc),

b. the speed and capacity of transmissions,

c. whether or not transmissions may proceed simultaneously in both directions,

d. and how a physical connection to the medium is made.

2. **Data Link Layer:** It is the responsibility of the Data Link Layer to take the raw transmission capability offered by the Physical Layer and make it reliable. To do this the Data Link Layer breaks up the transfer data into frames. Through the use of various error detection algorithms, this framing structure enables the Data Link Layer to detect transmission errors. By far, the most pervasive technique used to detect these errors is the cyclic redundancy code (CRC).

   ISO defines two types of data link services, connection mode and connectionless mode. In the connection mode, the data link service facilitates the establishment of a logical connection, the negotiation of quality of service, the reliable transfer of data, and an expedited data service. In contrast, the connectionless mode provides all of the above services except the establishment of a logical connection. The ramifications of not establishing this logical connection are that the data link service may discard data units, duplicate data units, and deliver data units in an order which differs from that in which they were originally presented by the user.

3. **Network Layer:** The Network Layer provides a means of transferring data in a manner which is independent of the underlying network architecture. This responsibility dictates that the Network Layer offer the capability of transferring data across any sort of network or even a network of networks. To do this, the Network Layer performs the routing and relaying of data, establishes network connections to support this routing, facilitates error recovery by utilizing the error notification provided by the Data Link Layer, packetizes the data to be transferred and sequences the delivery of these data units. It is also the

responsibility of the Network Layer to implement congestion control within the network, and to detect and discard outdated, nomadic packets (i.e., lifetime control).

4. **Transport Layer:** The Transport Layer adds reliability to the otherwise unreliable datagram service provided by the network and datalink layers below it. The transport user (usually the Session Layer) submits arbitrarily large messages (Transport Service Data Units or TSDUs) to Transport for transmission. The TSDUs are segmented into smaller messages (Transport Protocol Data Units or TPDUs) whose size is appropriate for the underlying layers. A checksum is calculated for each message segment and a unique sequence number is assigned to each segment. A retransmission timer is started when the Transport Layer delivers the segment to the underlying Network Layer for transmission. The receiving Transport Layer acknowledges each segment with a special "ack" message. If the transmitter's Transport Layer fails to receive an acknowledgement for a segment by the time its retransmission timer expires, the Transport Layer stops the transmission stream and retransmits all messages beginning with the one whose acknowledgement is missing. In this way the Transport Layer creates a connection-oriented service (a "virtual circuit"). Messages are guaranteed to arrive at the receiver in order, without loss or duplication.

5. **Session Layer:** The Session Layer provides the user's interface to the Transport service. It manages the dialogue between two communicating Presentation Layer processes so that their exchange of data is organized and synchronized. This management involves providing an interface to enable specific options of the session connection to be negotiated. Moreover, in the context of managing a dialogue between the user and a machine or device, the Session Layer ensures that proper access rights are being observed.

6. **Presentation Layer:** The Presentation Layer is primarily concerned with the specific method in which data is represented. This focus touches upon issues such as text

compression/expansion, encryption/decryption, and the commonality of data representations. Within a heterogeneous network, the connected host machines may not share the same methodology of representing semantically equivalent data. Under these circumstances, communication is not possible unless a common methodology can be established. The Presentation Layer provides a means of negotiation that enables this establishment to be made, and subsequently transforms incompatible data representations into an agreed upon methodology. Hence, the Presentation Layer provides for the interoperability of heterogeneous networks and abstracts the issues of data representation from the Application Layer.

7. **Application Layer:** The Application Layer encapsulates the semantics of the data being exchanged. To the user, the Application Layer represents the means through which the OSI environment can be accessed. In this respect, the Application Layer provides functions and services that are generally useful in the support of distributed applications. File transfer and electronic mail services exemplify the kinds of protocols found within this layer.

Use of the Basic Encoding Rules relates exclusively to the Presentation Layer while the use of ASN.1 pertains to both the Application Layer and the Presentation Layer. However, with respect to the issue of evaluating ASN.1's ability to solve the disparate data representation problem, the relationship between ASN.1 and the Application Layer is unrevealing. Thus, it is the Presentation Layer that largely determines the manner in which ASN.1 and BER are used.

2.3 The Presentation Layer

As user data passes through the Presentation Layer its complexion changes significantly. To the layers beneath the Presentation Layer, the user data parameters of a service primitive appear as a mere sequence of octets.[4] These octets are uninterpreted by the lower layer protocol entities

that process them. In the Application Layer, the user data parameters typically correspond to complex data types that possess significant meaning to the application protocol standards that use them. The application entities must process the content of these values in detail in order to provide a requested service. Therefore, the nature of this change in the user data can be viewed as a bridge between the gap that separates syntax from semantics. It is the job of the Presentation Layer to facilitate this transition.

Two objectives of this task make it a difficult one. First, the Presentation Layer should provide this service in such a way that it does not overly determine the manner in which the data is represented in the Application Layer. Second, the manner in which the information content of a user data parameter is expressed should in no way determine the syntax of the octets. This decoupling of semantics and syntax represents the grass roots of the ASN.1 and BER solution. To understand how ASN.1 and BER achieve this decoupling, certain Presentation Layer concepts must be understood. These concepts are the focus of the following subsections.

2.3.1 Abstract Syntax

ASN.1 is a notation that formalizes the data types and data values of a protocol for purpose of standardization. Specifically, ASN.1 describes the informational content of both the user data parameters and control information that cross the interface between the Presentation Layer and the Application Layer. The most important characteristic of how ASN.1 presents this description is that it does so without influencing the representation of this data on either side of this interface. An instance of an ASN.1 description is called an **abstract syntax.**

4. The term octet is essentially a synonym for byte given that a byte always consists of eight bits.

2.3.2 Transfer Syntax

The data items that are passed from the Application Layer to the Presentation Layer will eventually become user data parameters of the Presentation protocol that will in turn cross the interface between the Session Layer and the Presentation Layer. However, before they cross this interface, these data items must be transformed into an uninterpreted sequence of octets. This transformation, or **encoding**, of the data values of an abstract syntax into a sequence of octets is called a **transfer syntax**. The necessary properties of any transfer syntax are that it carry the information described by the corresponding abstract syntax in a manner which is independent of the representation of data in any particular application entity, and that the reciprocal transformation, or **decoding**, of the transfer syntax into the data values of an abstract syntax be readily applicable.

2.3.3 Presentation Context

Over any given presentation connection, the Presentation Layer must associate each abstract syntax with a supporting transfer syntax. This enables the Presentation Layer to perform the translation between the user data parameters of the application protocols and the octet sequences. From within the Presentation Layer, each association forms a **presentation context**. To the user of the presentation service, namely an application entity, a presentation context identifies all of the abstract syntaxes that may be sent or received over a presentation connection. During the lifetime of a presentation connection, the Presentation Layer may be supporting more than one presentation context. All of the presentation contexts that have been negotiated for a given connection are referred to as the **defined context set**.

3. An ASN.1 and BER Tutorial

The most effective means of presenting the details of both ASN.1 and BER is to first provide a context through which these details may be better appreciated. To establish this context a hypothetical set of communication requirements relating to the NASA Space Station will be examined. An application protocol will subsequently be developed using ASN.1. As the hypothetical requirements are iteratively refined, the ASN.1 definition will increase in sophistication. After the finer details of ASN.1 are explored, the Basic Encoding Rules will be applied to typical data values of the newly created application protocol. However, before this protocol development commences, an overview of both standards is necessary.

3.1 Overview

The ASN.1 standard defines a language used to describe data values and data types. It is typically used by Application Layer protocols to define the types of their Application Protocol Data Units (APDUs). For example, protocols such as File Transfer, Access, and Management (FTAM) and Virtual Terminal (VT) use ASN.1. However, it is important to note that the use of ASN.1 is not necessarily restricted to the Application Layer. Theoretically, it could be used to define the Protocol Data Units (PDUs) of any layer.

In the ISO nomenclature, ASN.1 provides the means to define an **abstract syntax.** To understand this concept, it is useful to consider the term literally. In the formal academic sense, a *syntax* defines the legal sentential forms of a language. Within the context of communications,

one usually thinks of a syntax as defining the bit patterns used to represent data flowing across a medium. An *abstract* syntax, therefore, does not define these bit patterns, but rather it establishes a framework whereupon these bit patterns, called a **transfer syntax,** can be created. The manner in which they are created depends upon the encoding rules that are applied.

The Basic Encoding Rules standard defines a specific technique for encoding data. To use our previous ISO terminology, it defines a mapping from the abstract syntax, defined by ASN.1, into the transfer syntax. A BER encoding is represented as a sequence of **octets.** These octets are partitioned into 3-tuples, indicated in Figure 8:

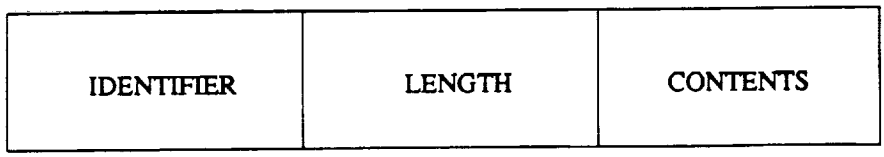


Figure 8. Encoding Format

The **identifier octet(s)** contain information regarding the type and form of the encoded data value. A **primitive** form indicates that the **contents octets** contain a direct representation of the data value. A **constructed** form indicates that the contents octets contain another embedded encoding. The **length octet(s)** determine the end of an encoding. They indicate how many contents octets represent the encoded data, or, if that this number is unknown, then they indicate that the contents octets are delimited by a reserved bit pattern called an **end of contents** (EOC) sequence. The contents octets contain a direct representation of the data value or another nested identifier-length-contents sequence.

As an analogy, if ASN.1 is viewed as the floor plan of a house, then the BER corresponds to the architect, and the Presentation Layer is the builder. The actual house represents the transfer syntax. Note that a floor plan indicates the generic structure of a house: the number of rooms, the identity of each room, and their positional relationships. This coincides with the kind of

information that ASN.1 provides about a data type. Consider that there are many different ways to build a house according to a given floor plan. Which way is chosen depends upon who the architect is and how this architect chooses to realize the floor plan. This choice is reflected in the set of blueprints generated. Likewise, we should not consider the BER to be the only means of defining a transfer syntax. Yet, at the present time, the BER represent the only architect *officially* in business.

Notice that if the floor plan of the house were to be changed, a new set of blueprints must be generated in order to rebuild the house. This reveals an important characteristic of ASN.1. When an Application Layer protocol is described using ASN.1, the Presentation Layer must be provided with the encoding/decoding knowledge required to support these defined data types. In other words, the house-builder must be given a new set of blueprints. If the ASN.1 description of this protocol is changed, new encoding/decoding information must be created. This is when the automated generation of blueprints (i.e., an ASN.1 compiler) becomes highly desirable.

Before describing what an ASN.1 compiler is, a word of caution is necessary. When it is said that ASN.1 provides a mechanism to define data values as well as data types, this statement has a tendency to foster misconceptions. With regard to the Presentation Layer, the implementation significance of the ASN.1 value assignment is entirely dependent upon its use as a default value; this is explained later. As for the Application Layer, value assignments simply provide a means of *documenting* specific APDU values. Therefore, do not interpret ASN.1's ability to define a data value as meaning that the actual ASN.1 notation is passed between the Presentation and the Application Layers at run-time. ASN.1 is merely a descriptive tool used to define Application Protocol Data Units (APDUs). The actual run-time syntax of an APDU depends upon the application and the host environment. The primary impetus for using ASN.1 is that it provides a standard means for the Presentation Layer to anticipate the structure of an APDU so that it may

correctly create and interpret the transfer syntax.

The purpose of an ASN.1 compiler is to automate the generation of logic required to encode and decode PDUs according to the transfer syntax. In other words, the ASN.1 compiler may be viewed as an automated architect. Given a floor plan (an ASN.1 description), an ASN.1 compiler generates a new set of blueprints for the builder (i.e., the Presentation layer). Clearly, the relative benefit of an ASN.1 compiler is directly proportional to the stability of the floor plan. For mature protocols such as VT and FTAM, the likelihood of significant modifications is very small. Therefore, the need for an ASN.1 compiler is not a compelling issue. However, in an environment where a protocol is evolving and changing, an ASN.1 compiler offers tremendous benefit.

Figure 9 depicts the integration of an ASN.1 compiler into an implementation. The source code processed by the compiler is the actual ASN.1 description of the data types of an Application Layer protocol. The object code (i.e., blueprints) consists of a set of encode and decode routines (file name *asn1.c*[5]), a run-time library (file name *runtime.c*), and an "include" file containing the corresponding APDU programming language declarations (file name *asn1.h*). The encode, decode and run-time routines are subsequently embedded within the Presentation Layer implementation. The APDU declarations file is referenced within both the Application and the Presentation Layers.

5. The names of the files generated by the compiler will not always be *asn1.c* and *asn1.h*. The names of these files always coincide with the name of the ASN.1 module.

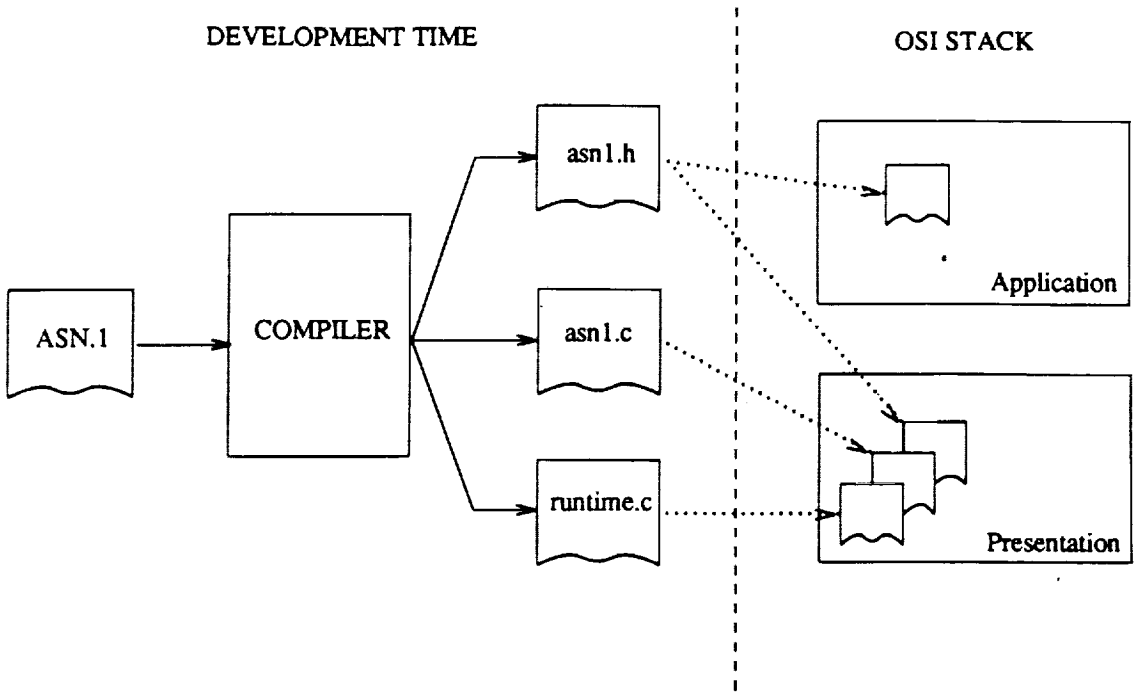


Figure 9. Using an ASN.1 Compiler

3.2 The Abstract Syntax Notation One (ASN.1)

Within this section the details of ASN.1 are explored. To begin this examination, a hypothetical yet simple set of data communication requirements relating to the NASA Space Station is examined. A protocol definition that supports these requirements will then be developed using ASN.1. As these requirements are subsequently refined the complexity of the protocol definition will increase. This evolving example serves as the focal point of this section.

3.2.1 A First Example

One of the Space Station's data communication requirements might entail the transfer of work requests and corresponding results. The execution of a particular scientific experiment is a perfect example of the possible connotation of a typical work request. If one were to describe an APDU representing this data type, it might comprise the following data items:

1. *Assigned-to:* identifying the individual who is to perform the work,

2. *Date:* identifying when the work is to be carried out,

3. *Description:* identifying the specific work to be done.

A typical result might consist of a simple indication of either success or failure. This very elementary model will provide us with a sufficient starting point.

This new protocol will be called Work Initiation and Management Protocol (WIMP). The ASN.1 definition of WIMP might look as follows:

```
Wimp DEFINITIONS ::= BEGIN

   Request ::= SEQUENCE {
      assigned-to IA5String,
      Date,
      description IA5String
   }

   Result ::= INTEGER
      -- success = 0, failure = -1

   Date ::= IA5String
      -- formatted as MM/DD/YY

END
```

Figure 10. ASN.1 definition of WIMP

The block of text in Figure 10 represents a **module** definition. A module is an ASN.1 construct enabling related type and value definitions to be logically grouped. Every module definition begins with a statement of the form:

<module name> DEFINITIONS ::= BEGIN

and ends with the keyword END. For a module corresponding to an international standard, it is recommended that its corresponding module name be of the form

ISOxxxx-yyyy

where xxxx is the number of the international standard and yyyy is a suitable acronym. As an illustration, in the *highly* unlikely event that this ASN.1 definition were to become an international standard, its module name might be ISO9999-WIMP.

The ASN.1 standard states that the layout of the notation itself is *not* significant. A type assignment or a value assignment may consequently span multiple lines. Likewise, the previously specified module header does not have to appear all on one line. The keyword BEGIN could have been placed on the following line if desired. Indenting is also permitted and in fact encouraged. Its proper use will dramatically increase the readability of the notation.

ASN.1 *is* case sensitive. All keywords such as DEFINITIONS, BEGIN, END, SEQUENCE, and INTEGER must appear in upper case. Certain classes of identifiers must also begin with either upper or lower case letters specifically. For example, a module name must always begin with an upper case letter. All of its subsequent letters may be expressed in either upper or lower case, and hyphens may appear between any two. Other instances of case sensitivity will be described as each relative construct is discussed.[6]

The module definition consists of three **type assignments.** Each defines a new ASN.1 data type and establishes a **type reference** that can be used to designate the type. All type references must begin with an upper case letter. The first type assignment defines the type reference *Request* as a SEQUENCE of three elements. The second and third assignments define the *Result* and *Date* types as an INTEGER and an IA5String (ASCII string), respectively.

---

6. The use of the word "identifier" above could be potentially confusing. Within this context, the term is being used in a manner that is consistent with the academic theory of programming language design. In other words, an "identifier" is a sequential group of symbols that does not represent a keyword, operator, separator, or delimiter. Unfortunately, clause 8.3 of ISO 8824 officially defines an **identifier** as any **named** form whose first symbol is always a lower case letter. In the previous context, this later definition was not being referenced.

Two classes of data types appear in this example: **simple** and **structured.** The INTEGER and IA5String data types are classified as simple while the SEQUENCE data type is structured. Simple types are atomic, meaning their form may not be decomposed. Structured types are defined by reference to other type(s); hence, they are decomposable. All three data types -- IA5String, SEQUENCE, and INTEGER -- are predefined in ISO 8824.

The ASN.1 SEQUENCE is a constructor notation used to model an *ordered* collection of variables whose number is known and modest and whose types may differ. Note that a SEQUENCE is not technically a type, but rather it represents a mechanism through which new types may be created. To think of this in programming language terms, a sequence data type may be viewed as the ASN.1 equivalent of a Pascal record or a structure declaration in C. In fact, if the above module definition were given to our ASN.1 compiler, the generated include file would contain a C structure declaration representing the corresponding APDU.

The three elements of the sequence in Figure 10 represent the name of the person who is to be assigned responsibility for performing the work request, the date that the request is to be executed, and a textual description of the work itself. All three of these elements are of the type IA5String, an ordered set of zero or more characters chosen from the International Reference Version of International Alphabet No. 5. In other words, the characters of an IA5String are ASCII.

The first and third elements are **named types** while the second is not. A named type consists of an **identifier** followed by a type reference. The use of named types is not required within an element list. Consequently, it is legal to omit the identifiers of any or all of the three elements. For instance, the Request data type could have just as easily been defined as indicated in Figure 11.

```
Request ::= SEQUENCE {
   IA5String,
   Date,
   IA5String
}
```

Figure 11. Request (without named types)

However, Annex E of ISO 8824 suggests that "a reference name should be assigned to every element whose purpose is not fully evident from its type." In this particular instance, the removal of these reference names is not advisable. Another consideration in favor of using named types is that the code generated by an ASN.1 compiler will be more readable when these types are used.

Notice that the second element refers to a type reference, *Date*, that has not yet been defined (actually it appears later in the definition). Forward references are allowed within a module definition. Consequently, type references may appear before the point at which they are defined.

Finally, two comments appear in our example. A double hyphen begins a comment, and either the end of the line or another subsequent double hyphen delimits it. Comments are an important aspect of the notation. Although their use bears no significance in determining the encoding of a data value, comments provide a valuable means of protocol documentation. Their use is strongly recommended.

3.2.2 Refining Our Requirements: A Second Example

Having seen how to create an ASN.1 module definition, the following refinements of the requirements are considered to improve the quality of the protocol.

1. The order of the elements within the *Request* type need not be considered significant; that is, these elements need not be sent in the same order that they are defined.

2. There may be a very large number of mundane, tedious chores that a user of this protocol

would always wish to assign to a particular individual by default. (Perhaps there will be a graduate student in the Space Station.) It would therefore be desirable to have a default value associated with the *assigned-to* element. This association would enable the specification of this particular value to be omitted when the desired name matches the default.

3. A mechanism to associate any given result with its original request is needed, otherwise the request and result transfers would have to occur in lockstep.

4. Certain requests may not require that an explicit result be reported. The addition of a new element, indicating when this condition holds true, would be desirable.

Considering these new requirements, a new ASN.1 definition of WIMP is given in Figure 12.

```
Wimp DEFINITIONS ::= BEGIN

   Request ::= SET {
      assigned-to [0] IA5String DEFAULT Grad-student
      to-begin-on [1] Date,
      id-number INTEGER,    -- must be a positive #
      result-required BOOLEAN,
      description [2] IA5String
   }

   Grad-student IA5String ::= "James Harvey"  -- who else?

   Result ::= INTEGER    -- failure = -1, success = request id #

   Date ::= IA5String    -- formatted as MM/DD/YY

END
```

Figure 12. A new definition of WIMP

The order dependency of the elements within the *Request* data type has been removed by the introduction of the ASN.1 SET type. Like the SEQUENCE type, the SET type models a collection of variables whose number is known and modest and whose data types may differ. It is another example of an ASN.1 structured type. The only difference between a set type and the

sequence type is that the collection of elements within a set is *unordered*. This modification, from a sequence type to a set type, fulfills the first requirement.

It is important to note that three elements of *Request* data type have been provided with explicit **tags** (the numbers appearing within the square brackets). Tagging is an extremely important concept in ASN.1. Its proper use may profoundly influence the efficiency and quality of a protocol definition. Since this concept relates more to the encoding of a data value, tagging is described in the next section. However, a few general comments are necessary to identify the importance of tagging elements within structured types, especially when the structured type is a set that contains elements of the same type.

In the previous overview, the basic format of a BER encoding was described as a sequence of identifier-length-contents octets, where the identifier octets indicate the form and type of the encoded data value. This identifier information specifically reflects the tag of the corresponding ASN.1 data type and is intended to signify that the encoded value is of this specific type. Consequently, every ASN.1 data type has an associated tag that may be expressed in either an explicit or an implicit manner. All of the previously defined data types have had associated tags.

Occasionally, the presence of the normal tags does not provide a sufficient context to enable a receiving Presentation Layer to unambiguously decode an encoding. Under these circumstances, additional tagging is required. This means of identification is especially important when the encoding is a set that contains elements of the same data type. Since the order of elements within a set is not significant, each element's tag must be unique. Otherwise, it would not be possible for the receiving Presentation Layer to determine which encoded value corresponds to which element within the definition.

With respect to the second requirement, a default value has been associated with the element *assigned-to* by the presence of the keyword DEFAULT followed by the **value reference** *Grad-*

student. This value reference is defined in the **value assignment** appearing beneath the definition of *Request.* All value assignments are of the form:

value_reference Type ::= Value

The implications of defining a default value are that both the original APDU and the transferred encoding may omit the specification of this particular element. In such instances, the receiving Presentation Layer will generate the appropriate default value as it performs the decoding.

Finally, the boolean element *result-required* and the integer element *id-number* have been added to the definition of *Request.* Both of these are predefined (universal) ASN.1 data types. Their purpose, with regard to the last two requirements, should be self-explanatory.

Unfortunately, the previous example of a value assignment is too simple in that it does not illustrate some of the more interesting notational characteristics. Therefore, a more complex case that relates to the current definition of WIMP is examined below. Consider how a value of the *Request* data type might be expressed. The value assignment of *Typical-request-value* demonstrates this in Figure 13.

```
Typical-request-value Request ::=
   {assigned-to "James D. Harvey",
    to-begin-on "03/15/89",
    id-number 1,
    result-required FALSE,  -- typical student attitude
    description "Write a thesis"}
```

Figure 13. A more complex value assignment

Notice that any value that corresponds to a structured type is enclosed in braces and that each element value within a structured value is preceded by its corresponding reference name. Technically speaking, the appearance of these reference names is not required. However, whenever complex data types are involved, their inclusion increases readability.

3.2.3 A More Realistic Example

As the final iteration of the example, a more realistic set of requirements is considered. These requirements will motivate a fairly sophisticated ASN.1 definition and will represent the complexity one might encounter in a real application. The new requirements are as follows:

1. It would be desirable to have the option of not specifying who is to carry out a given work request if we so desire. For instance, the user of this protocol might wish to have a particular request assigned to whoever is available at the time the work is scheduled to commence. The specification of the *assigned-to* element should therefore be optional.

2. Certain tasks may require the participation of more than one individual. Thus, the *assigned-to* element should indicate an unbounded number of name values. Furthermore, it is important that the user be given the ability to associate an authority hierarchy with the individuals that are specified. In other words, the manner in which these individuals are expressed should denote a "chain of command."

3. The date (or rather time) that a request is to be executed should be expressed in a more accurate manner. A mere date is not very specific.

4. A Result should indicate more than just success or failure. It should also indicate the names of the individual(s) who attempted to perform the task. This may differ from the original request. The contents of a Result should also vary according to the outcome. If a work request is executed successfully, the time of completion should be given. If a request fails, an explanation of the failure would be desirable.

5. Each request should possess an indication of its relative importance.

6. Certain work requests may be of a proprietary nature and the ability to indicate when this condition exists is desirable. Furthermore, in these instances it might be necessary to

encrypt the *description* of a request itself.

Considering these new requirements, a more realistic version of WIMP can now be developed. The new ASN.1 definition that accommodates these requirements is given in Figure 14:

```
Wimp DEFINITIONS ::= BEGIN

   Request ::= [APPLICATION 0] SET {
      assigned-to [0] Participants OPTIONAL,
      start-time [1] UTCTime,
      id-number [2] INTEGER,
      result-required [3] BOOLEAN,
      importance [4] INTEGER {background(0), normal(1), urgent(2)},
      proprietary [5] BOOLEAN,
      description CHOICE {
         unencrypted IA5String,
         encrypted EXTERNAL
      }
   }

   Result ::= [APPLICATION 1] SET {
      successfully-completed BOOLEAN,
      Participants,
      request-number INTEGER,
      CHOICE {
         time-of-completion UTCTime,
         reason-for-failure IA5String
      }
   }

   Participants ::= SEQUENCE OF IA5String
     -- listed in order of decreasing authority

END
```

Figure 14. A more robust WIMP

The first element of the *Request* data type, *assigned-to,* has been designated as OPTIONAL, meaning that the corresponding APDU may or may not possess a value for this element. This satisfies the new requirement that the user may not wish to specify who is to perform a given work request. Syntactically, the keyword OPTIONAL is used in exactly the same manner as the keyword DEFAULT.

The type of the *assigned-to* element has also been changed from a simple IA5String to the structured type *Participants*. *Participants* is defined as a SEQUENCE OF IA5Strings. Like the previous example of a sequence, the order of elements within a sequence-of type is considered significant. Yet, all of the elements of a sequence-of must be of the same type, and the number of these elements is unbounded. The sequence-of type models a collection of variables whose types are the same, whose number is unknown or large, and whose order is significant. It is clear that this fulfills the second requirement. Since the order of the elements within the *Participants* type is significant, one can list an arbitrary number of individuals in order of decreasing authority. The application protocol has the assurance that this order will be preserved during transfer.

With respect to the third requirement, the *start-time* element has been introduced in lieu of our earlier date. Its type is UTCTime, a predefined ASN.1 **useful type** that provides a standard means of representing time. ISO 8824 defines the UTCTime type as:

```
UTCTime ::= [UNIVERSAL 23] IMPLICIT VisibleString
```

Figure 15. Useful Definition of UTCTime

The VisibleString is a character subset of ASCII, and the notation [UNIVERSAL 23] is the tag. The keyword IMPLICIT indicates a tag inheritance property that will be explained later.

The UTCTime type may be used to represent a time value expressed as a sequence (in non-ASN.1 terms) of juxtaposed characters. The syntactic format of a UTCTime data value can assume one of the following forms:

YYMMDDhhmmZ

YYMMDDhhmmssZ

YYMMDDhhmm +- hhmm

YYMMDDhhmmss +- hhmm

Figure 16. Syntactic forms of UTCTime

The first two consist of a calendar date followed by a time specification whose precision is either to the minute or to the second. The second two represent a local time and a differential from coordinated universal time (UTC).[7] Note that YY, MM, DD, hh, mm, and ss all stand for the digits that one would naturally assume. The notation "+-" refers to the alternative condition: either the character "+" or the character "-". Finally, the character Z (for Zulu) serves to distinguish the first two formats from the latter two which represent local time values and the local differential. Regardless of which format is used, this type provides the protocol with a more specific concept of time. Thus, the third requirement is satisfied.

The *Result* type has been drastically modified to meet the specifications of the fourth requirement. It is now a SET consisting of four elements. The first indicates whether the corresponding work request was completed successfully. The second contains the names of the individuals who attempted to perform the request. The third identifies the request to which the result corresponds, and the fourth element introduces a new structured type, the CHOICE.

The ASN.1 choice type is used to model a variable whose type may vary within the bounds of a known and modest set of alternatives. Each element appearing within the choice type indicates one such alternative. In the previous example, the fourth element consists of either a *time-of-*

7. UTC used to be referred to as Greenwich Mean Time.

completion value or a *reason-for-failure* value.

The choice type is analogous to a union declaration in C. One can think of our *Result* type as a variant record. The *successfully-completed* element corresponds to what is traditionally referred to as the tag field, and each element within the choice type represents a specific variant. In fact, if this definition was given to the ASN.1 compiler, it would generate a C struct declaration for the *Result* set type and an embedded union declaration for the choice type element. Yet unlike the C union, the ASN.1 choice is, by requirement, self describing. Consequently, the element *successfully-completed* and the element *proprietary* are redundant.

The fulfillment of the fifth and sixth requirements is reflected in the last three elements of the *Request* type. The *importance* element is an integer value indicating the relative priority of a request. The accompanying **named number list** (the text enclosed in braces) indicates the domain of meaningful values and their respective connotations. These named numbers are not significant in the definition of the type. Their purpose pertains to the value notation exclusively, although they do provide a valuable means of documentation. The *proprietary* element is a boolean value indicating whether a request is proprietary. According to this value, it is assume that the element *description* is either encrypted or unencrypted. The unencrypted version is simply an IA5String while the encrypted value is of the predefined, useful type EXTERNAL.

To explain how the EXTERNAL type facilitates this encryption, a brief digression is necessary. One of the primary services of the Presentation Layer is the negotiation of transfer syntaxes. Before any *useful* data may be exchanged across a presentation connection, the two presentation protocol entities that wish to communicate must first agree on the use of a transfer syntax. Since each is aware of its user's abstract syntax and the available encoding rules that it is capable of applying, agreement is simply a matter of reaching consensus on the preferred transfer syntax. When this negotiation process has been completed, the association of an abstract syntax

and a transfer syntax is referred to as a **presentation context.** [3]

The second concept that must also be understood is the definition of an **object identifier** and an **information object.** An information object is defined by ISO 8824 as "a well-defined piece of information, definition, or specification which requires a name in order to identify its use in an instance of communication." The ASN.1 standard itself is an information object. An object identifier is a value used to designate an information object. It is distinguishable from all other such values because each object identifier uniquely identifies its corresponding information object. Object identifier is a predefined universal type of ASN.1.

The creation of each individual value of the object identifier type is performed in a very formal manner. Only certain registration organizations possess the necessary authority to associate an object identifier with an information object. The domain of each respective organization's authority obeys a tree-structured hierarchy. The manner in which an object identifier value is expressed also reflects this structure, described in Annexes B, C, and D of ISO 8824. A partial view of this structure is given in Figure 17.

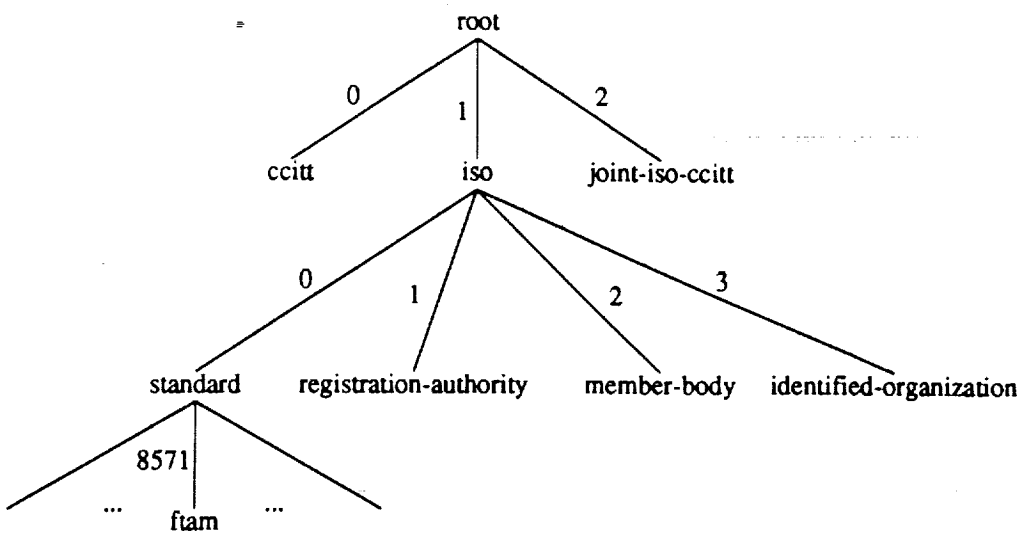


Figure 17. Object Identifier Tree

Each interior node of the tree represents a domain of authority. Each leaf represents a specific information object. Both the name of each node and the numbers associated with each arc provide a means of uniquely identifying a specific information object. Each value of the object identifier type consists of a sequence of these arc and/or node values. For instance, the information object FTAM may be expressed as:

{iso standard 8571}

Figure 18. Object Identifier Value for FTAM

An object identifier value therefore represents a method of identifying a path from the root node to a descendent. More important, an object identifier value may denote any registered abstract syntax and a supporting set of encoding rules. This later point is particularly important with respect to the encryption example.

The purpose of using the ASN.1 external type is to force the current presentation context to change. The external type itself is represented as an ASN.1 sequence, indicated in Figure 19.

```
EXTERNAL ::= [UNIVERSAL 8] IMPLICIT SEQUENCE {
   direct-reference OBJECT IDENTIFIER OPTIONAL,
   indirect-reference INTEGER OPTIONAL,
   data-value-descriptor ObjectDescriptor OPTIONAL,
   encoding CHOICE {
      single-ASN1-type [0] ANY
      octet-aligned [1] IMPLICIT OCTET STRING,
      arbitrary [2] IMPLICIT BIT STRING
   }
}
```

Figure 19. EXTERNAL type definition

For the purpose of understanding the encryption example, it is sufficient to simply recognize that the external type contains an encoded value (expressed as a CHOICE type), along with either an object identifier value that identifies the new abstract syntax and encoding rules or an integer value that identifies what the new presentation context should be.

The encryption example could be constructed as follows:[4]

1. An object identifier for BER already exists within the object identifier tree.

2. A second set of encoding rules could be registered explicitly. The algorithm associated with these new rules would consist of applying the Basic Encoding Rules and then applying an encryption algorithm to the resulting bit stream. Obviously, the necessary decryption knowledge would be distributed selectively.

3. Two presentation contexts could be subsequently established; one to support just ISO 8825, and one to support both ISO 8825 and these new encoding rules.

The encrypted description of a work request can now be embedded within an encoding. When the receiving Presentation layer attempts to decode a value of this external type, it can make the appropriate adjustment to its presentation context.

If this description is not clear, the reader might find the following analogy helpful.[8] If a

presentation connection represents a dialogue between two individuals, then the presentation context would represent the agreement they must make regarding what language they are going to speak. Assuming that the basic phonetic properties of any natural language are not sufficient to determine its identity, these two people must agree on which language or languages they are going to use before "striking up a conversation." Let us assume that they agree to speak in either English or French and that presently they are speaking English exclusively.

Consider what would happen if the following situation arose. In the course of the dialogue, one of these individuals would like to express the cliche, "That's life!". However, instead of uttering this English phrase, this person would like his comment to capture a specific ambiance. He therefore decides to say *"C'est la vie!"*. In this analogy, the embedded French phrase corresponds to the encrypted data value of the external type. Its value must consist of a representation of the phrase itself and an indication that a change in the interpretation context is necessary. In other words, the listener must be explicitly told that some French is about to be spoken if he is to interpret the comment correctly. (Remember, it is assumed that phonetics is not an identifying characteristic.) This illustrates the primary purpose of the ASN.1 external type. It forces a change in the current presentation context so that a data value of a different transfer syntax can be correctly interpreted.[9] In this French example, the phrase value would provide either an object identifier designating that the French "encoding rules" must be applied or a presentation context identifier indicating that the current presentation context must be changed to French.

---

8. This analogy was provided by Maurice Smith who is the International Representative of the ANSI X3T2 Data Interchange Sub-committee.

9. It is important to recognize the EXTERNAL type serves as only a temporary "escape" to a new presentation context. The presentation layer protocol directly supports more long term context control mechanisms.

3.2.4 Other ASN.1 Types

To complete this presentation of ASN.1, a brief description of each remaining ASN.1 type is given that was not depicted within any of the previous examples.

3.2.4.1 The BIT STRING Type

The BIT STRING type may be used to model a variable whose binary format is unspecified and whose length, in bits, is either unspecified or not a multiple of eight. Consequently, the binary data of a bit string may not fit into an integral number of octets. A bit map indicating set membership is a perfect example of a variable that would use the bit string type. The definition of *Light* in Figure 20 illustrates how the BIT STRING type is used.

```
Light ::= BIT STRING {red(0), orange(1), yellow(2), green(3),
                      blue(4), indigo(5), violet(6)}
-- An instance of light is defined by its spectrum colors;
-- a bit value of one indicates that the corresponding color is present
```

Figure 20. Using a BIT STRING

The text between the braces, referred to as a **named bit list**, does not influence the definition of the type. It is used solely in the value notation and provides a means of documenting the type.

3.2.4.2 The OCTET STRING Type

The OCTET STRING type may be used to model a variable whose format is unspecified and whose length, in bits, is unspecified but known to be a multiple of eight. The definition of the EXTERNAL type, Figure 19, uses the OCTET STRING type to model the *octet-aligned* alternative of its *encoding* element. The OCTET STRING type may also be used to model specific character string types which are not already predefined by ASN.1 (see section 4.4.6).

3.2.4.3 The NULL Type

The ASN.1 NULL type represents a valueless placeholder. Within a sequence, for instance, the NULL type may indicate the absence of a specific element. Annex E of ISO 8824 provides the following example:

```
PatientIdentifier ::= SEQUENCE {
    name VisibleString,
    roomNumber CHOICE {
        INTEGER,
        NULL -- if an out-patient
    }
}
```

Figure 21. Using the NULL Type

In this context, the NULL type merely provides an alternative means of expressing that the *roomNumber* element as OPTIONAL. However, the two methods should not be viewed as equivalent. In this case (where a NULL type is used), the length of the corresponding encoding will be longer.[10]

3.2.4.4 The SELECTION Type

The SELECTION type may only be used in conjunction with a CHOICE type. It is used to create a new type which is derived from the selection of an alternative within a choice type. Consider the following CHOICE type:

10. It is not necessarily true that using NULL in lieu of OPTIONAL will always yield a longer encoding. If similar types were to appear in the SEQUENCE and OPTIONAL is used, or if the SEQUENCE was instead a SET, explicit tagging would be required to disambiguate the definition.

```
Outcome ::= CHOICE {
   time-of-completion UTCTime,
   reason-for-failure IA5String
}
```

Two selection types referring to this choice are illustrated in Figure 22.

```
Previous-results ::= SEQUENCE {
   last-success time-of-completion < Outcome,
   last-failure reason-for-failure < Outcome
}
```

Figure 22. Using the SELECTION Type

The first element, *last-success*, has been assigned the selection type that is represented by the name of the corresponding element within the choice type (*time-of-completion*), the less than sign, and the name of the choice type itself (*Outcome*).

3.2.4.5 The ANY Type

The ANY type acts as a placeholder for additional standardization. It is used to model a variable whose type is either unknown or specified within another standard. When the ANY type is used, additional specifications regarding the data types and semantics that are to fill the ANY field should be given prior to an instance of communication. The definition of the EXTERNAL type, Figure 19, uses the ANY type to model the *single-ASN1-type* alternative of its *encoding* element.[11]

11. Note that the ANY type is currently the focus of a considerable amount of controversy. The issue of leaving placeholders for another standard is currently unresolved. Therefore, the appearance of the ANY type is quite likely to change in the future.

3.2.4.6 Character String Types

ASN.1 defines eight distinct string types whose values are sequences (in non-ASN.1 terms) of zero, one or more characters selected from some predefined character set. These eight string types are:

1. **NumericString:** strings consisting of the digits 0..9 and the space character,
2. **PrintableString:** strings consisting of alphanumeric characters, the space character, and any of the following characters:

   ( ) ' + , - . / : = ?
3. **TeletexString:** strings consisting of characters suitable for Teletex terminals (see CCITT Recommendation T.61),
4. **VideotexString:** strings consisting of characters suitable for Videotex terminals (see CCITT Recommendations T.100 and T101),
5. **VisibleString:** strings consisting of alphanumeric characters, the space character, and any of the following characters:

   " : = , { } < . ( ) [ ] - '
6. **IA5String:** strings consisting of ASCII characters,
7. **GraphicString:** strings consisting of characters taken from all G (graphic) sets defined in ISO 2375 and the space character,
8. **GeneralString:** strings consisting of characters taken from all G (graphic) sets and C (control character) sets defined in ISO 2375 and the space character.

3.2.4.7 Useful Definitions

The ASN.1 standard provides four definitions that it considers to be useful in a number of

applications: **GeneralizedTime**, **UTCTime**, **EXTERNAL**, and **ObjectDescriptor**. The only one of these useful types that has not been illustrated within an example as of yet is the GeneralizedTime type. Like the UTCTime type, a GeneralizedTime value is represented as a VisibleString. It specifies the date and time as either a local time, a UTC time, or a combination of the two.

3.3 Basic Encoding Rules (BER)

The Basic Encoding Rules standard, ISO 8825, defines a specific technique for encoding data values corresponding to ASN.1 data type definitions. As mentioned in the overview, a BER encoding consists of a sequence of octets partitioned into an identifier-length-contents tuple, indicated in Figure 8. Within this section, the bit-level details of how this is accomplished are explained. But first, some numbering conventions must be established.

3.3.1 Numbering Conventions

To explain the details of an encoding it is often necessary to refer to specific bits within an octet. To do this, the same numbering scheme used in ISO 8825 is employed. Specifically, the bits of any octet will be numbered from eight to one, going left to right. The significance of each bit increases as one moves from right to left. It will also be necessary to refer to specific octets within an octet sequence. Here, the reverse numbering order is used. If n octets represent an encoding, the leftmost octets will be numbered one, and the rightmost will be numbered n. Figure 23 illustrates this convention.

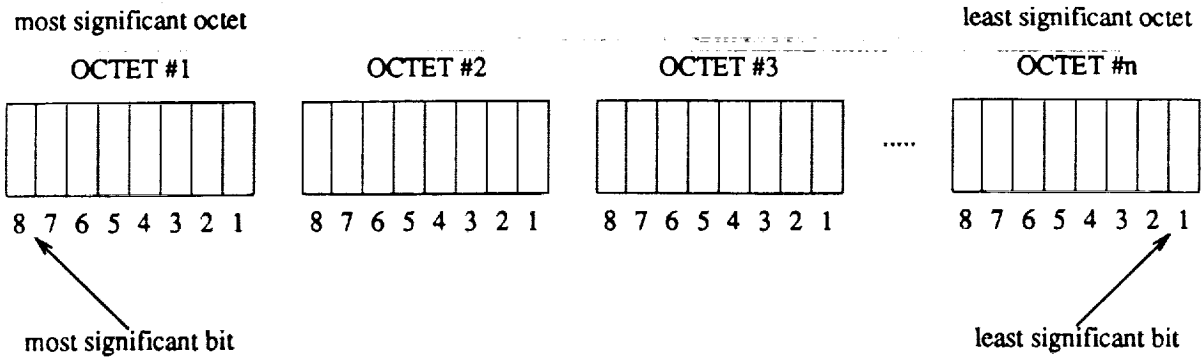


Figure 23. Bit and Octet Numbering

3.3.2 Tagging

It is appropriate that the examination of the Basic Encoding Rules begin by analyzing the structure and the content of the identifier octet(s). This requires an understanding of the concept of a tag. Four classes of tags may be associated with any element or data type in ASN.1: universal, application, context-specific, and private. Data types possessing a universal tag are predefined by ISO 8824. Like most programming languages, these predefined types provide a means through which other type definitions may be constructed. Table 1 lists all the ASN.1 universal types along with their respective tag numbers.

tag number	type name
1	BOOLEAN
2	INTEGER
3	BIT STRING
4	OCTET STRING
5	NULL
6	OBJECT IDENTIFIER
7	OBJECT DESCRIPTOR
8	EXTERNAL
9-15	(reserved for addenda)
16	SEQUENCE, SEQUENCE OF
17	SET, SET OF
18	NumericString
19	PrintableString
20	TeletexString
21	VideotexString
22	IA5String
23	UTCTime
24	GeneralizedTime
25	GraphicString
26	VisibleString
27	GeneralString
28-...	(reserved for addenda)

TABLE 1. ASN.1 Universal Types

Application class tags are assigned to types defined by other standards. Within any given standard, the same application class tag is never assigned to more than one type. For example, the *Result* data type in Figure 14 was assigned the tag application class, number 1. The private class tags may be assigned to only those types not defined within an International standard. ISO 8824 describes their use as "enterprise specific." The context-specific class tags, on the other hand, may be freely assigned to any type or element within a definition. As its name indicates, the interpretation of a context-specific tag depends upon the context in which it is used. The most common application of context-specific tags is to elements within a structured type. We have already seen examples of this. The element *assigned-to* of the *Request* type defined in Figure 12 was assigned the context-specific tag number 0.

Every type defined with ASN.1 has an associated tag. A tag value consists of a tag number

and its class. The purpose of this tag is to distinguish a data type within a given context. It is neither uncommon nor illegal for the same tag to be assigned to different types within the same standard provided that no more than one instance of this tag can occur within the same given context. If this condition is violated, the ASN.1 definition is ambiguous.

3.3.3 The Identifier Octet(s)

The identifier octets denote the tag and form of an encoded data value. An identifier octet sequence can assume two formats. Which format to use in a given case depends upon the magnitude of the tag number. If the tag number falls within the range 0..30 inclusively, then the corresponding binary value may be placed within a five bit field, thus enabling the entire identifier information to fit into one octet. If, on the other hand, the tag number exceeds 30, additional octets must be used. Figure 24 indicates the layout of the single octet format.

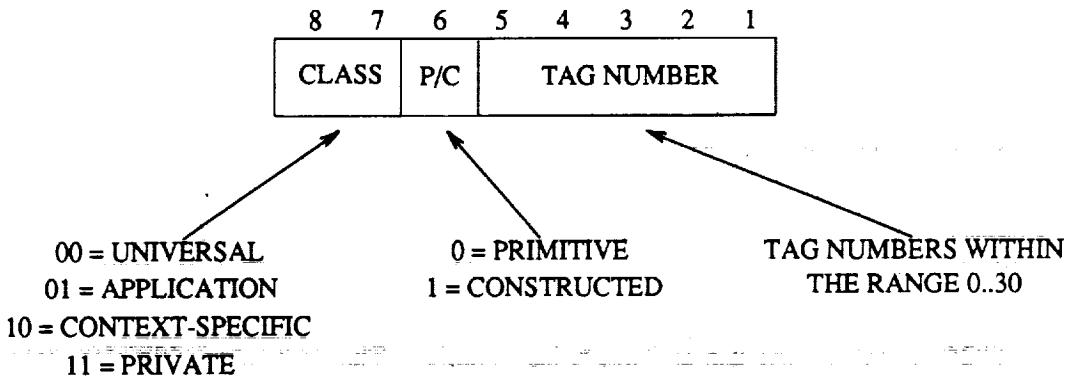


Figure 24. Identifier Octet (low tag number)

As illustrated, three information fields are contained within the identifier octet. The meaning of each is as follows:

1. **Class:** Bits 8-7 indicate the tag class of the encoded data value.

2. **Form:** Bit 6 indicates whether the encoded value is primitive or constructed. A primitive

form indicates that the contents octets contain a direct representation of the data value. A constructed form indicates that contents octets are the complete encoding of another data value. In other words, the subsequent contents octets contain embedded identifier-length-contents sequences.

3. **Tag Number:** For tag numbers falling within the range 0 to 30 inclusive, bits 5-1 of the leading (and only) octet designate this value. For tag numbers greater than 30, bits 5 through 1 contain the value 11111. This reserved bit pattern indicates that an extension of additional octets is required to hold the tag number. Bits 7-1 of each subsequent octet whose 8 bit is set to 1, up to and including the first octet whose 8 bit is set to zero, will be concatenated to form the binary tag number value. Figure 25 graphically illustrates this.

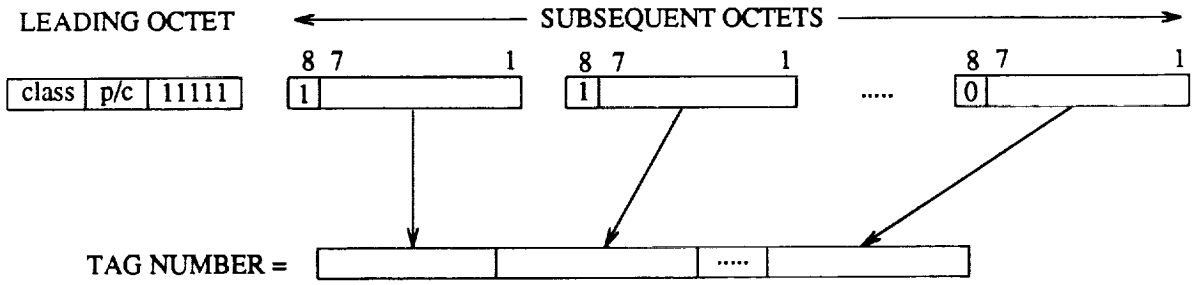


Figure 25. Identifier Octet (extended tag number)

3.3.4 The Length Octet(s)

The purpose of the length octets is to determine the end of an encoding. They explicitly indicate how many contents octets have been used in the encoding, or, alternatively, they signify that this length is unknown but deducible. In the explicit case, they contain the binary value corresponding to the exact number of contents octets that follow. In the case where this number is unknown, they contain a reserved bit pattern indicating that the contents octets are delimited with a special EOC sequence. An EOC sequence consists of two octets whose binary values are

zero.

Like the identifier octet(s), the length octet(s) may be expressed in more than one format: the short form, the long form, and the indefinite form. The use of a specific format is determined by three conditions: the form of the encoding (primitive or constructed), whether the number of contents octets is known in advance and the magnitude of this number. Primitive encodings are restricted from using the indefinite form since this would preclude the appearance of two consecutive "zero octets" within their contents octets. However in the case of a constructed type, the EOC octets always fall at the point in the encoding where the next identifier octet would be. Since zero is not a valid identifier octet (the UNIVERSAL 0 tag does not exist) there is no ambiguity. The choice of which format to use with constructed encodings is left to the user's discretion. Figure 26 illustrates the layout of these three forms.

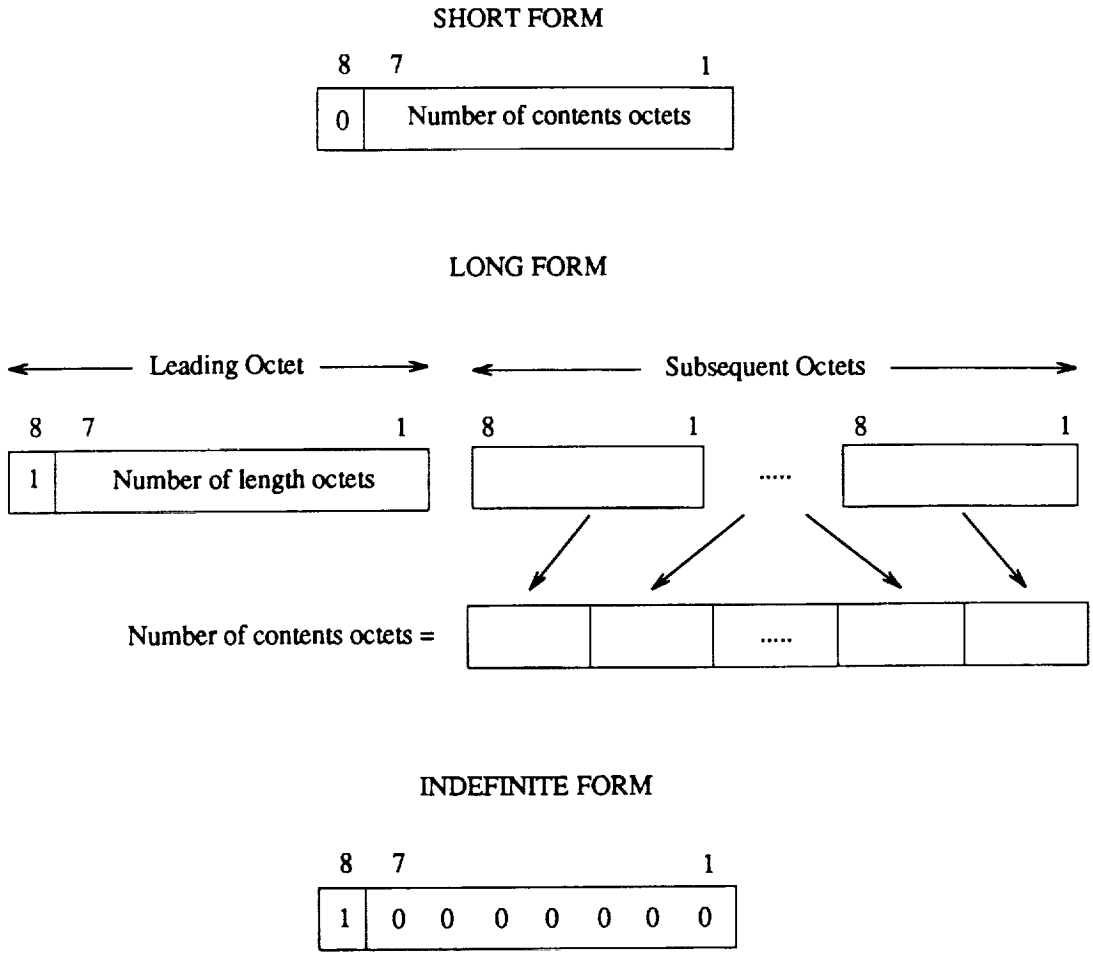


Figure 26. Length Octet Forms: short, long and indefinite

In the short form, the number of octets that the length information occupies is one. Bit 8 is required to be zero, and bits 7-1 contain the number of contents octets. Obviously, this form may be used only when the number of contents octets is less than or equal to 127. In the long form, the number of octets that the length information occupies can be anywhere from 2 to 127. In the leading octet, bit 8 is always set to 1, and bits 7-1 indicate the number of subsequent length octets required. Since the bit pattern 11111111 has been reserved for possible future extension, the maximum number of subsequent octets is 126. As illustrated in Figure 26, these subsequent octets are concatenated to form the binary value indicating the number of contents octets used in the encoding. Finally, the indefinite form requires only one octet containing the reserved bit

pattern indicated above. In relation to the other formats, this bit pattern represents the long form with zero subsequent length octets. From a logical perspective, this makes sense. No need for subsequent length octets exists since the contents octets are delimited by an EOC sequence.

3.3.5 The Contents Octet(s)

In a primitive encoding, the data value is directly represented by the contents octets. This may not, and in many instances will not, be exactly the same as the original native representation, depending on the host environment, the data type, and the magnitude of the value itself. For example, ISO 8825 specifies that negative integers are always in two's complement form and that the character values of an IA5String are in ASCII.[12] In a constructed encoding, the contents octets do not contain a direct representation of the data value, but instead contain further encodings. These nested encodings can in turn be constructed if necessary.

3.3.6 Examples

This section illustrates the content and the structure of the contents octets by examining the encodings of typical values pertaining to some of our previous ASN.1 definitions.

3.3.6.1 Encoding an Integer Value

The easiest example to illustrate would be the encoded values of the *Result* data type appearing in Figure 10. According to the comment below its definition, a success is represented by the value 0, and a failure is represented by -1. The encoding of a success value (0) is depicted in Figure 27:

12. Many other characteristics of ISO 8825 also influence this change in representation. For example, integers are always encoded in the minimal number of octets, etc.

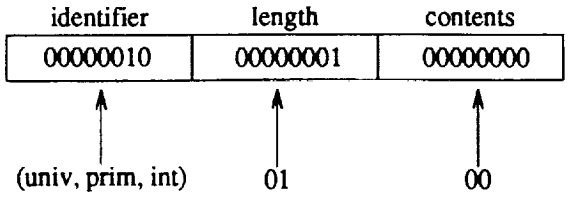


Figure 27. An encoding of the integer value Zero

The value representing failure (-1) is indicated in Figure 28:

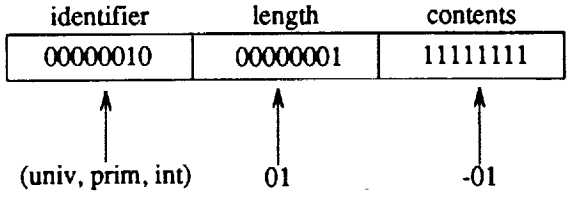


Figure 28. An encoding of the integer value Negative One

Each labeled box represents a single octet, and the binary values that they enclose are the actual bit values of the encoding. All of the other textual items are garishments that have been added to clarify the example.

Referring to Table 1, the tag of an ASN.1 integer type is a universal class number 2. Since this is not a tagged value, its form is primitive. Both of the identifier octets indicate these values. The length octets are in the short form and indicate that only one contents octet is required to represent the data value. Because these values are so small, the number of contents octets is technically *required* to be one. Clause 8.2 of ISO 8825 states that "if the contents octets of an integer value encoding consist of more than one octet, then the bits of the first octet and bit 8 of the second shall not all be ones; and shall not all be zero." This ensures that any integer encoding, whether positive or negative, will always occupy the least number of octets. Note that negative numbers are represented in the two's complement form.

In all future examples the encodings will not be presented in their binary form. Instead,

textual abbreviations are used to represent the identifier octet(s) (as above), decimal numbers are used to designate the length octets, and the contents octets are represented in a form resembling the data type being encoded.

3.3.6.2 Encoding a Sequence

As a more substantial example, consider *Request* that appears in Figure 10. A data value of this type consists of a simple sequence of three IA5Strings. For the typical value:

{"John Doe", "03/25/89", "Plant growth experiment"}

its encoding would be as follows:

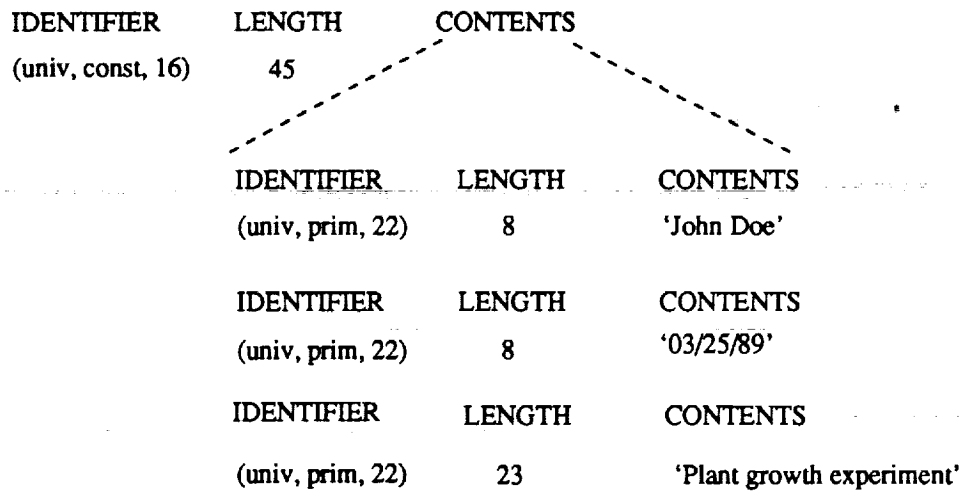


Figure 29. An encoding of a sequence value

The first identifier octet signifies that the type of the encoded data value is a universal class number 16. As indicated in Table 1, this corresponds to the sequence type. Since sequences are structured, the form is constructed and the contents octets consequently contain embedded identifier-length-contents tuples. In the above diagram, indenting is used to represent this nesting. The length octet of the outer most tuple indicates that the total number of contents octets is 45. This includes all octets associated with the nested tuples. The three embedded encodings

are of the type universal class 22. As indicated in Table 1, this tag number corresponds to the type IA5String. Their contents octets would contain the appropriate ASCII values.

3.3.6.3 A More Complex Encoding

As a final example, the encoding of a hypothetical value of the *Result* data type appearing in Figure 14 is given below. Assuming that this value is in response to our previous work request,[13] for the result value:

```
{successfully-completed FALSE,
 {"John Doe"},
 request-number 100,
 reason-for-failure "John lacks green thumb"}
```

its encoding would be as follows:

13. Ignore the fact that these two type definitions appear in different versions of WIMP.

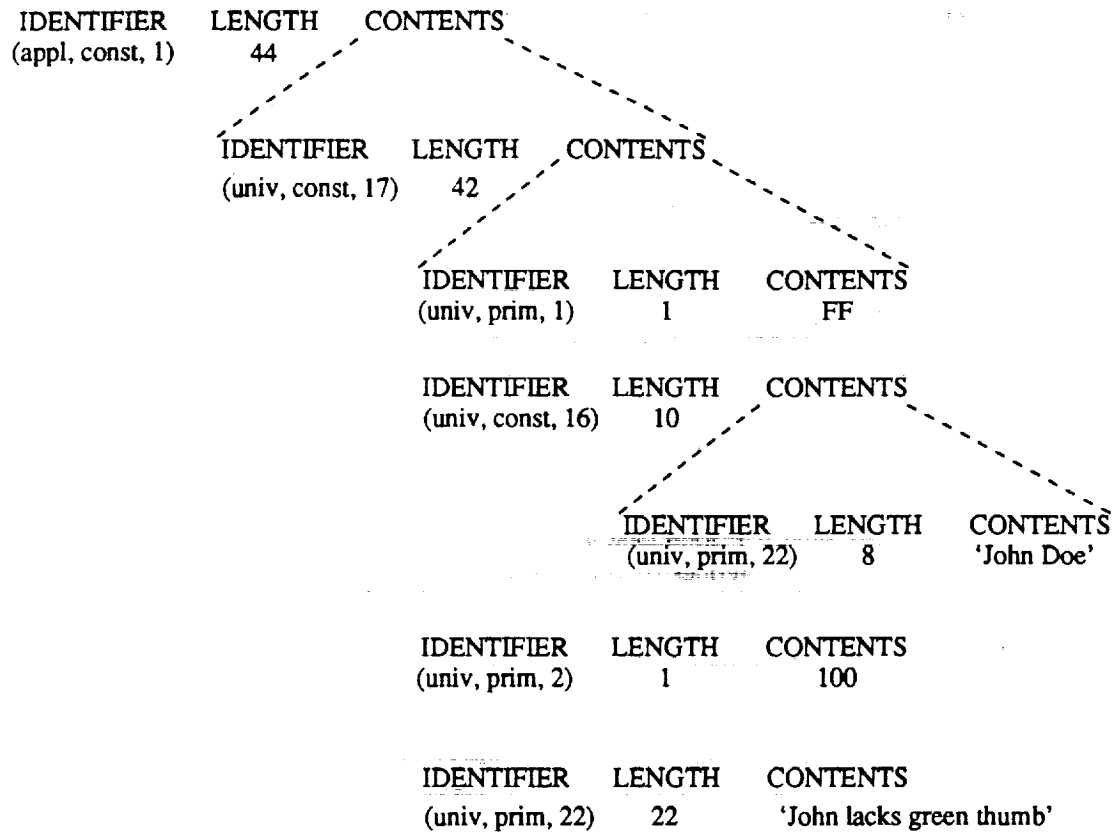


Figure 30. Encoding a result value

This encoding might appear somewhat verbose, or even redundant in places. This reflects the relationship between constructed encodings and tagged values, that is, values corresponding to a type definition explicitly tagged. The first identifier octet denotes that the tag of the encoded value is an APPLICATION 1. From the original ASN.1 definition we know that this tagged type is a set of four elements. However, before the encodings for these four elements can appear, the encoding for the set type (i.e. UNIVERSAL 17) must come first. This reveals an important aspect about tagging, namely, an explicit tag does not supplant the existing one but merely augments it. Although it is known in this context that a WIMP data value with a tag of APPLICATION 1 is a set of four elements, this information is not implicit with respect to an encoding. Therefore, each of the explicit tags increases the length of the encoding. This characteristic can be changed by adding the IMPLICIT keyword to the type definition.

3.3.7 The IMPLICIT Keyword

The IMPLICIT keyword may be used in an ASN.1 type definition to yield a more economical encoding. As a feature of ASN.1, it is an example of one way in which ISO 8824 and ISO 8825 are tied together. This, in a sense, violates the abstraction of the data types by making an issue of the encoding process visible to the user of ASN.1. ISO 8825 states that if the keyword IMPLICIT does not appear within the type definition of a tagged value, then the form of its encoding shall always be constructed. This was the case in the previous example. If, on the other hand, the IMPLICIT keyword is used, then the form of the encoding will be constructed only if the base encoding is constructed; it shall be primitive otherwise. This enables the encoding of a tagged value to connote type information otherwise requiring an additional embedded encoding. The following example will clarify this explanation.

In the definition of *Result,* it might be preferable that the tag value APPLICATION 1 indicate that the encoded data type is a set, thus allowing the removal of the embedded encoding pertaining to the UNIVERSAL 17 tag. The addition of the IMPLICIT keyword makes this possible:

```
Result ::= [APPLICATION 1] IMPLICIT SET {
    successfully-completed BOOLEAN,
    Participants,
    request-number INTEGER,
    CHOICE {
        time-of-completion UTCTime,
        reason-for-failure IA5String
    }
}
```

Figure 31. Adding the IMPLICIT keyword

This new definition would yield the more compact encoding given in Figure 32.

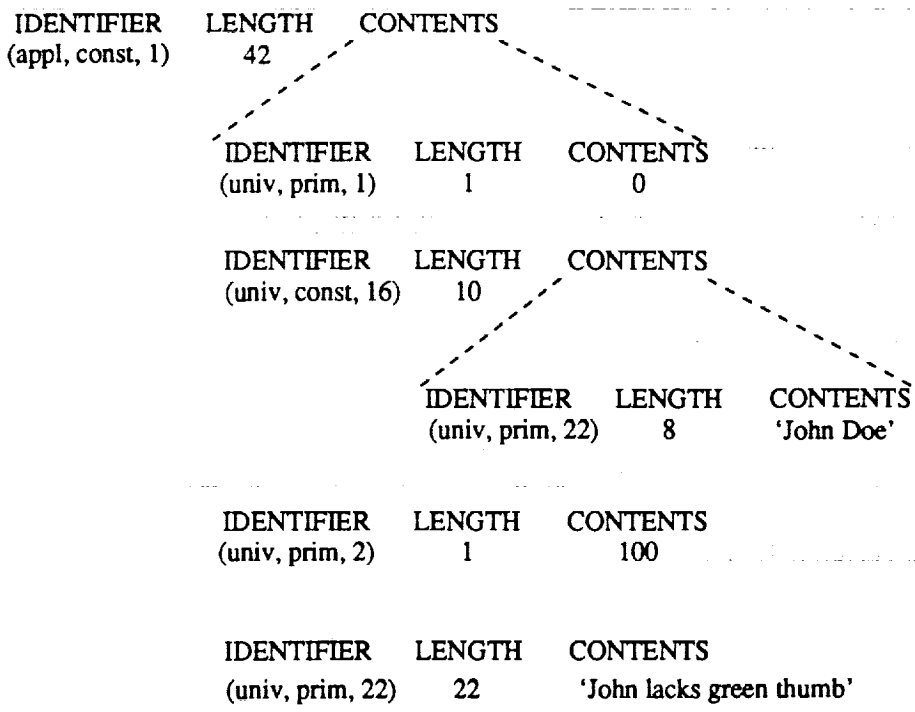


Figure 32. A New Encoding of Result

Notice that the total length of our encoding is now two octets shorter.

3.4 Pending Modifications

All ISO standards are subject to revisions that occur on a four year cycle. For mature standards, the modifications resulting from each cycle seldom constitute major changes. However, considering the relative youthfulness of both ASN.1 and BER, the changes associated with their first revision will most likely be quite significant. The draft addendums that define these proposed modifications are ISO 8824/DAD1[5] and ISO 8825/DAD 1.[6] The highlights of each of these proposals are discussed within this section along with the escalating controversy over the ASN.1 macro notation.

3.4.1 Tag Defaults

Experience in using ASN.1 indicates that the IMPLICIT keyword is used more often than not. Moreover, the current notation supporting the concept of implicit versus explicit tagging is asymmetric: the keyword IMPLICIT is defined while the keyword EXPLICIT is not. To alleviate both of these problems, ISO 8824/DAD 1 proposes a new notation whereupon either the IMPLICIT keyword or the EXPLICIT keyword may be applied to all tags within a module definition by default. The specification of this tag default option appears immediately after the keyword DEFINITIONS in the module header. For instance, if the user wanted all of the tags within the WIMP module to be IMPLICIT by default, its module header would be changed as follows:

```
WIMP DEFINITIONS IMPLICIT TAGS ::= BEGIN
```

Figure 33. A Module with the IMPLICIT Tag Default

Conversely, all of the tags within the WIMP module could be defined as explicit by simply substituting the keyword EXPLICIT for the keyword IMPLICIT. In all cases, EXPLICIT may be used in exactly the same manner as IMPLICIT. Consequently, individual tag specifications may override any default by using either keyword as necessary. When no tag default is specified, EXPLICIT is assumed.

3.4.2 Enumerated Types

Within one of the previous definitions of WIMP, Figure 14, the *Request* sequence type contains the integer element *importance*. One problem associated with this definition of *importance* is that the domain of its meaningful values is expressed as a named number list. Since named numbers have no influence on the definition of a type, a compiler generated implementation may not use this information. Consequently, the encode and decode functions

produced by the compiler will not check if values corresponding to the *importance* element fall within the proper range (i.e., 0..2).

ISO 8824/DAD 1 proposes that an enumerated type definition be added to ASN.1. Its tag would be the universal class, number 10. Using the suggested syntax, our previous *importance* element could be defined as indicated in Figure 34.

```
importance ENUMERATED {background(0), normal(1), urgent(2)}
```

Figure 34. An Enumerated Type

The encoding of a value of this enumerated type is defined to be that of the integer value with which it is associated.

3.4.3 Importing and Exporting

Although an example of this has not shown, in any given module definition it is currently possible to reference types and values defined in other modules. As an illustration, if another module definition were to require the use of WIMP's *Request* data type, it could do so by specifying the name of the module, followed by a "." and the name of the type:

```
New_request_type ::= Wimp.Request
```

Figure 35. An External Type Reference

ISO 8824/DAD 1 proposes a new notation that would enable a user to exert explicit control over the visibility of type references and value references. The proposal requires that a module definition be partitioned into three sections: an EXPORT list, an IMPORT list, and an assignment list. As an example, assume that the *Participants* data type of the previous WIMP definition were already defined within another module, *People*, and that it is desired that the definitions of the *Request* and the *Result* data types be visible to other protocol standards. The new definition of

WIMP would be as follows:

```
Wimp DEFINITIONS ::= BEGIN

   EXPORTS Request, Result

   IMPORTS Participants FROM People

   Request ::= [APPLICATION 0] SET {
      assigned-to [0] Participants OPTIONAL,
      start-time [1] UTCTime,
      id-number [2] INTEGER,
      result-required [3] BOOLEAN,
      importance [4] INTEGER {background(0), normal(1), urgent(2)},
      description CHOICE {
         unencrypted IA5String,
         encrypted EXTERNAL
      }
   }

   Result ::= [APPLICATION 1] SET {
      successfully-completed BOOLEAN,
      Participants,
      request-number INTEGER,
      CHOICE {
         time-of-completion UTCTime,
         reason-for-failure IA5String
      }
   }

END
```

Figure 36. Using EXPORT and IMPORT

3.4.4 Reals

The most glaring deficiency associated with the current definition of ASN.1 is the absence of real types. To fill this void, ISO 8824/DAD 1 and ISO 8825/DAD 1 propose that a new real type be added with the tag universal class, number 9. The keyword REAL is used to designate the type as illustrated in Figure 37.

```
Angle-in-radians ::= REAL
```

Figure 37. Example of a REAL type assignment

A value of a real type (in the ASN.1 notation) is expressed as a 3-tuple of integers. The first integer represents the mantissa, the second indicates either base 2 or base 10, and the third represents the exponent. As an example, a value assignment for π is given below:[14]

```
pi REAL ::= {31415, 10, -4}
```

Figure 38. Example of a REAL Value assignment

The three special values positive infinity,[15] negative infinity,[16] and 0 are also defined and may also be used in place of the bracketed 3-tuple.

For the sake of brevity, the method of encoding a real type will not be presented in its entirety. The curious reader should refer to 8825/DAD 1 document for a full description of this process. Simply note that the method used is not the IEEE floating point standard.

3.4.5 Subtypes

The most substantial modification proposed by ISO 8824/DAD 1 is the introduction of an ASN.1 subtyping capability. The changes relating to this new feature are quite extensive with respect to ISO 8824. The following examples should give the reader a general feel for what is being proposed.

---

14. The second element of the REAL tuple is simply the base which is raised to the specified power. This is in no way related to the representation base.
15. indicated by the keyword PLUS-INFINITY
16. indicated by the keyword MINUS-INFINITY

The draft addendum defines a subtype as "a type whose values are specified as a subset of the values of some other type (the parent type)". A subtype specification is composed of alternatives where each alternative is a value set or a constraint. A subtype is created by either explicitly enumerating a subset of values taken from a parent type, constraining the range of values from the parent type, constraining the size of a parent type, or by using any combination of these three methods.

In the previous definition of WIMP, Figure 14, there are several instances where a subtyping capability might be useful. First, within both the *Result* and *Request* data types, the protocol designer may want to constrain the possible values of an *id-number* to fall within the range 0..127. This would enable its encoded value to occupy only one byte. Second, it may be desirable to limit the number of *Participants* that may be assigned to any given request to 10. The two type assignments within Figure 39 could be used to meet these new requirements.

```
Request-number ::= INTEGER (0..127)

Participants ::= SEQUENCE SIZE (1..10) OF IA5String
```

Figure 39. Using Subtypes

3.4.6 The Macro Notation

Annex A of ISO 8824 defines a macro notation that can be used to extend ASN.1. Although it is currently an official part of the standard, the details of the ASN.1 macro notation are presented here because they are the focus of a considerable amount of controversy. Their present disposition within the ASN.1 standard is precarious. This is exemplified by the fact that the X3T2 subcommittee, which is the United States constituent responsible for maintaining the ASN.1 standard, has developed the official position that the use of macros be "strongly deprecated."[7] Consequently, the future of the ASN.1 macro notation is uncertain.

The macro notation allows the user of ASN.1 to define a new notation through which ASN.1 types may be constructed and referenced, and values of these types may be specified. The macro definition process requires that the user specify a new and complete syntax for defining all types supported by the macro, a corresponding syntax for specifying a value of this type, and the resulting type and value for all instances of this macro value notation. The specific rules that determine how this definition process is expressed are quite tedious and are therefore not presented. Instead, an example that pertains to the definition of WIMP is explored.

Suppose the designer of the WIMP protocol wishes to define a new data type that represents a primary request and an alternative request. The alternative is to be attempted only in the event that the primary request fails. Certainly it is feasible to represent this new data type as a SEQUENCE of two elements. However, for reasons of personal taste, this person would like to express this new type with a syntax of his own design. The macro notation would be used to accomplish this as indicated below:

```
REQUEST-WITH-ALTERNATIVE MACRO ::= BEGIN
   TYPE NOTATION ::=
      "plan-a" "="
         type (Plan-a-type)
      "plan-b" "="
         type (Plan-b-type)
   VALUE NOTATION ::=
      "(" "plan-a" "="
         value (Plan-a-value Plan-a-type)
      "," "plan-b" "="
         value (Plan-b-value Plan-b-type)
      <VALUE SEQUENCE {Plan-a-type, Plan-b-type} ::=
         {Plan-a-value, Plan-b-value}>
      ")"
END
```

Figure 40. A Macro Definition

This macro could subsequently be used to define types and values as follows:

```
Request-pair ::= MACRO REQUEST-WITH-ALTERNATIVE
   plan-a = Request
   plan-b = Request

Request-value Request-pair ::=
   (plan-a = ...,
    plan-b = ...)
```

Figure 41. Using a Macro Definition

In the above Figure, the elipses refer to any value of the Request data type.

Many problems associated with the macro notation have been currently identified. For example, since macro definitions may contain subsequent macro references, the ability to parse the macro notation is questionable. Also, ambiguities relating to the resulting type and tag of a macro may arise.[8] With respect to the future, the current definition of the ASN.1 macro notation is quite likely to change. These problems are explored further in chapter 5.

4. The ASN.1 Compiler

Now that most of the details of both ASN.1 and BER are understood, it is important to establish an understanding of how their use might be realized within an implementation. The details of an ASN.1 compiler are described within this section.

Before delving into these details it is necessary that the following objective be clearly stated. The author does not consider this compiler implementation to be *the* solution to the ASN.1 problem and the reader should not interpret the ensuing explanations as such. As mentioned earlier, the usefulness of an ASN.1 compiler can be limited, especially when the protocol being implemented is fairly stable. In these situations it is practical to write the encoding and decoding routines by hand as this often yields a faster implementation. An ASN.1 compiler is therefore not always the "best" means of developing an implementation. Secondly, there are many viable approaches to the problem of incorporating this encoding and decoding functionality into a Presentation Layer implementation. This compiler represents one of many possible solutions. Its value depends upon the insight it provides into the relationship between these two standards and the OSI Reference Model.

4.1 Physical Specifications

The compiler is written in the C programming language and is approximately 5000 lines in length. Its front end was developed using the Unix utilities *Lex* and *Yacc*. The compiler accepts an ASN.1 module definition as input and generates two C files as output: an include file

containing the C declarations of the APDU's, and a code file containing the two C functions *encode* and *decode*. A run-time library also provides a melange of general purpose routines. Unfortunately, the compiler does not support the entire ASN.1 standard; the macro notation, character sets other than IA5Strings, useful types, and external references are not presently implemented.

4.2 Generating Declarations

To create a transfer syntax, the ASN.1 compiler depends upon a precise knowledge of the APDU representations. It is therefore appropriate that the compiler assumes the responsibility of creating these declarations on behalf of the Application Layer. This provides a more robust implementation since it ensures that the ASN.1 data type definitions will be always consistent with the actual APDU representations. Clearly this is desirable, considering that the relative benefit provided by an ASN.1 compiler hinges upon its ability to minimize the effects that modifications to the abstract syntax may cause. The reader's understanding of this mapping from the ASN.1 definitions to the APDU declarations is most important; it represents the first bridge between an ASN.1 definition and a working implementation.

Assuming that the reader is familiar with the C programming language, the clearest means of describing this aspect of the compiler is through an example. Let us examine the APDU declarations generated from the module definition of WIMP that appears in Figure 10. These are shown in Figure 42.

```
typedef char *Date_apdu;

typedef struct {
   char *assignedto;
   Date_apdu _unnamed_1;
   char *description;
} Request_apdu;

typedef int Result_apdu;

typedef struct {
   enum {Request, Result, Date} which_apdu;
   union {
      Request_apdu Request;
      Result_apdu Result;
      Date_apdu Date;
    } apdu;
} Wimp_apdu;

typedef struct {
    int length;
    byte *value;
} Wimp_encoding;
```

Figure 42. Declarations of WIMP APDU's

Although the above declarations do not represent the entire contents of the declarations file, this is sufficient to illustrate the important facts.

Each type assignment within an ASN.1 module definition produces a corresponding C typedef declaration. The *Request* data type, for instance, is represented by the typedef structure *Request_apdu*. As one would expect, it contains three members, each corresponding to one of the three elements within the original ASN.1 data type definition. Typedef declarations for the data types *Date* and *Result* also appear. All of these typedef declarations are subsequently referenced as members of a union that is embedded within the *Wimp_apdu* structure. *Wimp_apdu* is a variant record that represents any APDU of our WIMP protocol. Each of its variants corresponds to one of the data types defined within the original ASN.1 module. The *which_apdu* member identifies the type that is currently being represented by the union.

There are two subtle but important aspects of the above declarations that should be noted. First, the order of these typedef declarations does not correspond to the original ASN.1 definition. This is because forward references, while permitted within ASN.1, are not permitted within C. Consequently, the declaration of *Date_apdu* must precede the declaration of *Request_apdu*. Second, notice that the name of the second member of the *Request_apdu* structure is *_unnamed_1*. Since the second element of the original ASN.1 definition of the *Request* data type was not named, the corresponding C name must be supplied by the compiler itself. This illustrates why the use of named types within an ASN.1 element list enables the compiler to generate more readable C code.

4.3 Generating Code

The compiler generates two routines which are to be subsequently integrated into the Presentation Layer. Since actual C code of each is very detailed it will not be presented. The reader may refer to Appendix A where a complete listing of the code generated for this particular example is given. Within this section the logical operation of each function is discussed in a very general sense. The corresponding function declarations are given below.

```
encode_Wimp (decoding, encoding)
        Wimp_apdu *decoding;
        Wimp_encoding *encoding;

decode_Wimp (encoding, decoding)
        byte *encoding;
        Wimp_apdu *decoding;
```

Figure 43. The Encoding and Decoding Functions

4.3.1 Encoding

The encoding function accepts the *decoding* argument as input and produces the *encoding* argument as output. The encoding process occurs in two phases. The purpose of the first phases is to calculate all of the length octet values of the encoding to be generated and to allocate an encoding buffer of the proper size. This task is performed by examining the contents of each value within the given APDU and making the appropriate run-time calls. These computed length values are inserted into a table which already contains the type octet values for each type that has been defined in the ASN.1 module. These values are subsequently extracted from this table in the later phase as the actual encoding is generated. The fact that the inner length octets of an ASN.1 encoding determine the values of the outer length octets explains why this length calculation phase is necessary. In other words, it is not possible to build an encoding from the inside out since the starting offset within the encoding buffer is unknown. The second phase focuses upon building the actual encoding. The type and length values from the previously built table are inserted into the encoding buffer and the actual values of the APDU are passed to the appropriate run-time routines which insert the contents octet values.

4.3.2 Decoding

The decoding function accepts the *encoding* argument as an input and produces the *decoding* argument as output. The decoding process is controlled by a finite state machine, implemented as a state table. Each entry of the state table contains an expected type octet value and a set of transitions. The finite state table for the Wimp module of Figure 10 is given below:

```
struct decode_state {
   struct {
      class c;
      form f;
      int id;
   } type;
   int match_state;
   int diff_state;
   int end_state;
   boolean matched
} Wimp_fsm[] = {
   {{universal, primitive, 22}, -1, 1, 0, false},
   {{universal, primitive, 2}, -1, 2, 0, false},
   {{universal, constructed, 16}, 3, -2, 0, false},
   {{universal, primitive, 22}, 4, -2, 0, false},
   {{universal, primitive, 22}, 5, -2, 0, false},
   {{universal, primitive, 22}, -1, -2, 0, false}
};
```

Figure 44. The Decoding Finite State Machine

The *match_state* element represents the transition that is to be made when the current type octet matches the type octet of the given state. As one might guess, the *diff_state* element represents the transition that is to be made when these two type octets differ. The *end_state* is necessary when the value being decoded requires that a set of states be executed an undeterminable number of times; this is the case when the value is a set type, a set-of type, a sequence-of type, or a recursive type.

The actual decoding process consists of a large switch statement that is iteratively executed until either the decoding is successfully completed, or the decoding fails.

4.4 The Run-Time Library

Most of the "bit-level" details of the encoding and decoding process are contained in the run-time library. This library consists of a set of C routines that perform very specific functions. The nature of these functions does not vary with respect to the ASN.1 definition; that is, the work

performed by these run-time routines is applicable to the encoding and decoding of almost all ASN.1 definitions. An overview of these run-time routines is given below.

The ASN.1 compiler's run-time library consists of the following routines:

1. *Dec_typlen* : This function decodes the type and length octets of an an encoding. It supports both the five bit form as well as the extended form of the type octet(s) as well as the short, long, and indefinite forms of length octet(s).

2. *Enc_typlen* : This function decodes the type and length octets of an encoding. It supports both the five bit form as well as the extended form of the type octet(s) as well as the short, long, and indefinite forms of length octet(s).

3. *Len_len* : This function determines the length of a length octet value. In other words, it determines how many length octets are required to hold a given length value. This routine is called by the encoding routine when it is computing the length of the encoding.

4. *Int_len* : This function determines the number of contents octets required to encode a given integer value.

5. *Enc_int* : This function inserts the encoding of an integer value into the contents octet(s) of an encoding. In accordance with clause 8.2 of ISO 8825, the number of contents octets produced is always the minimum required to represent the integer value.

6. *Dec_int* : This function returns the integer value represented by the contents octet(s) of an encoding.

7. *Enc_bool* : This function inserts the encoding of a boolean value into the contents octet(s) of an encoding.

8. *Dec_bool* : This function returns the boolean value represented by the contents octet(s) of an encoding. A boolean value in C is declared as an unsigned char.

9. *Enc_ia5str* : This function inserts the encoding of a IA5String value into the contents octet(s) of an encoding.

10. *Dec_ia5str* : This function returns the IA5String value represented by the contents octet(s) of an encoding.

11. *Enc_bstr* : This function inserts the encoding of a BIT STRING value into the contents octet(s) of an encoding.

12. *Dec_bstr* : This function returns the BIT STRING value represented by the contents octet(s) of an encoding.

13. *Enc_ostr* : This function inserts the encoding of a OCTET STRING value into the contents octet(s) of an encoding.

14. *Dec_ostr* : This function returns the OCTET STRING value represented by the contents octet(s) of an encoding.

15. *Obj_id_len* : This function calculates the number of contents octets required to encode a given OBJECT IDENTIFIER value.

16. *Enc_ostr* : This function inserts the encoding of a OBJECT IDENTIFIER value into the contents octet(s) of an encoding.

17. *Dec_ostr* : This function returns the OBJECT IDENTIFIER value represented by the contents octet(s) of an encoding.

4.5 Performance

As a more substantial test, the F-INITIALIZE-request PDU of the FTAM Application protocol[9] was given to the ASN.1 compiler. A listing of this ASN.1 definition appears in Appendix B. With the exception of converting two Graphic String data types to IA5Strings and

modifying one tag,[17] the FTAM definition used to conduct this performance measurement should represent the overhead one would expect to encounter in reality. Although the other PDUs of FTAM were reduced to integer data types, their explicit tags were left intact. Since these types correspond to transitions within the decoding finite state machine that are never be made, the reduction of these types is irrelevant to the measured performance.

Given the definition in Appendix B, the ASN.1 compiler generated a declaration file of 194 lines and a C code file of 2849 lines. Running on a Sun 3/140 workstation, the time to encode the F-INITIALIZE-request PDU was approximately 5.11 milliseconds, and the time to decode was approximately 4.97 milliseconds.[18]

17. The explicit tag of the Protocol-Version data type was changed from [0] to [9]. This was necessary due to an ambiguity within FTAM (see section 5.1).

18. Timings were obtained using the Unix *time* command whereupon the reported user and system times were combined. The Sun workstation was dedicated to a single user when these measurements were taken.

5. Observations

Through the process of building the compiler many insights into the ASN.1 and BER were obtained. This chapter presents these observations in an effort to illuminate the answer to the question of how well ISO 8824 and ISO 8825 solve the problem of network heterogeneity. When approaching this issue it is essential that one bear in mind the kinds of characteristics that determine the context that makes such an evaluation possible: efficiency, clarity, applicability, and ease of implementation.

5.1 Ambiguity

One of the more surprising discoveries that resulted from our experience with the ASN.1 standard is the fact that the concept of ambiguity is not well defined. In the introduction of ISO 8824 a footnote indirectly addresses this issue in the context of tagging. It states:

> Encoding rules always carry the tag of the type, explicitly or implicitly, with any representation of a value of the type. The restrictions placed on the use of the notation are designed to ensure that the tag is sufficient to unambiguously determine the actual type, provided the applicable type definitions are available.

The reference to *the* tag (singular) in the above statement suggests that if ever a specific tag value indicates more than one type in any given context, then the ASN.1 definition is ambiguous. If this is indeed the correct interpretation, then the logic required to decode an encoding is LR(0).[19]

19. Other ASN.1 compilers refer to decoding as "parsing".

This coincides with the finite state machine approach that is used to perform the decoding within our ASN.1 compiler. Yet, this same interpretation of ambiguity also suggests that the official ASN.1 definition of FTAM is ambiguous!

Looking at the partial definition of FTAM that appears in Appendix B, notice that the data type *PDU* is a choice consisting of three untagged alternatives. Since these elements do not possess explicit tags, an encoding of this data type is identical to the encoding of the selected alternative. Furthermore, notice that the *FTAM-Regime-PDU* alternative of the *PDU* data type is also a choice whose first element, *F-INITIALIZE-request*, is assigned the tag context 0. This means that the first tag of an encoding of the *F-INITIALIZE-request* PDU will always be context 0. Now note that the *Protocol-Version* data type that appears later in the module also possesses the explicit tag context 0. Since the definition of this type appears at the outermost lexical level, as does the definition of *PDU*, both of these data types represent potential PDUs. Consequently, when the generated FTAM decoding routine encounters a context 0 tag as the first type octet of an encoding, it has no way of knowing whether or not the value being represented is a *Protocol-Version* PDU or a *F-INITIALIZE-request* PDU. In this particular case, a two tag lookahead is necessary to disambiguate the encoding.

From the name *PDU* it is natural to assume that this data type is the root of the FTAM definitions and that all FTAM PDU's originate from this type. This heuristic could therefore be used to resolve this particular ambiguity. However, this is clearly an assumption since there is no construct of ASN.1 being used to indicate that this condition holds true. In as much as forward references are allowed in the notation, it is not possible to make this assumption based on the mere fact that this definition appears first. Consequently, all data types that appear at the outermost lexical level of a module must be considered PDUs in their entirety and the ambiguity remains. In fact, since the elements of the *PDU* data type do not possess explicit tags, the absence

or presence of this type definition does not influence the formulated encodings in any way; in other words, this data type is extraneous with respect to how an FTAM encoding is built and interpreted.

It is true that the FTAM standard does not intend that the *Protocol-Version* data type be considered a PDU by itself. In reality it is a supporting type definition that is referenced as a **named type** within other PDU definitions. Yet, the compiler has no means of making this distinction based on the notation itself.[20] Therefore, every type definition that is not lexically embedded within another type definition must be treated as a PDU. As a general approach to the issue of ambiguity, requiring more than a single tag lookahead would require any ASN.1 compiler to generate an LR(k) implementation. This would almost certainly prevent the realization of efficient implementations.

The ASN.1 definition of what constitutes an ambiguous instance of the notation requires clarification.

5.2 Library Management

The unrestricted manner in which type or value definitions within other ASN.1 modules may be referenced presents another area of the ASN.1 standard that appears to be inadequately defined. When an ASN.1 user wishes to reference a type or value that has been defined within another module the External Reference construct may be used. As explained in section 3.4.3, an external reference consists of the specification of the module name where the definition appears and the actual name of the desired type or value. A proposal to enable the ASN.1 user to exert

20. Using the heuristic that any data type mentioned within another type is necessarily a supporting type would preclude recursive definitions.

explicit control over the importing and exporting of definitions is currently under consideration in the pending draft addendum. However, a potential problem which has been overlooked by the definition of this external referencing capability involves the potential for mutually dependent module definitions. Consider the following modules:

```
Module-A DEFINITIONS ::= BEGIN
   Type-A1 ::= BIT STRING
   Type-A2 ::= SEQUENCE {
      Module-B.Type-B1
   }
END

Module-B DEFINITIONS ::= BEGIN
   Type-B1 ::= OCTET STRING
   Type-B2 ::= SEQUENCE {
      Module-A.Type-A1
   }
END
```

Figure 45. Mutually Dependent Modules

In this example, two ASN.1 modules are mutually dependent since each references a data type that is defined within the other.[21] This potential for mutual dependencies requires that an ASN.1 compiler generate partially complete intermediate code files and makes the automated processing of these definitions extremely difficult. This problem is attributable to the absence of a well defined library management concept within ISO 8824.

5.2.1 Linear Elaboration

The problem of mutually dependent modules can be solved if ISO 8824 were to establish a requirement of linear elaboration.[10] The Ada programming language effectively utilizes this concept to prevent the possibility of mutual dependencies among compilation units. *Elaboration*

21. Mutually dependent modules appear in the X.500 series of standards.

is defined as the process by which an entity is brought into existence. According to the definition of Ada, this marks the point at which the name of a declarative item is bound to its type. The name of an Ada entity may not be used before the elaboration of the declarative item that declares this entity takes place. With respect to compilation units, the concept of linear elaboration requires that a noncircular ordering of all compilation units referenced, either directly or indirectly, by a given program must exist. If no such ordering can be found, the program is illegal.

This same requirement could be applied to the ASN.1 standard to prevent the possibility of mutual dependencies.

5.2.2 Useful Types

A set of predefined data types, called **useful types**, is specified in section three of ISO 8824. Four data types are defined: Generalized time, Universal time, the External type, and the Object Descriptor type. One problem associated with the manner in which these types are defined concerns their disposition relative to the rest of the standard. Specifically, the means through which their names are made visible to all module definitions is not clear. Hence, their relationship to the ASN.1 standard itself is unclear. The development of a library concept would also serve to solidify the disposition of these types.

Like Ada's package STANDARD, a predefined module of these useful types should be defined. This would consequently allow any ASN.1 module to explicitly import these types whenever their use is required. Alternatively, this importing of these types could be defined as implicit as is the case with package STANDARD. In any regard, the disposition of these types as a predefined environment would be clarified and therefore strengthened if a module were to be formally defined.

5.3 Efficiency versus Generality

The development of any standard seems to entail a perpetual series of compromises. Issues concerning generality and efficiency are typically in conflict and a balance of the two is often the best that can be achieved. For the most part, ASN.1 and BER adequately strikes this balance. However, there are particular instances where the issue of generality has been favored over considerations of efficiency to a questionable degree.

5.3.1 Encoding Integers

As stated in section 3.3.6.1, ISO 8825 requires that all integer values be encoding in a minimum number of octets. This requirement prohibits integer encodings from being unnecessarily large and prevents the pathological case where an integer value may be transferred with an arbitrarily number of leading octets that contain either all zeros or all ones. Nonetheless, the cost of this decision is expensive with respect to efficiency. It has been shown that the encoding and decoding of an ASN.1 integer value, in contrast to a simple memory copying technique, decreases the transfer rate by a factor that ranges from 5 to 20 depending upon the host system.[11] Moreover, in this same set of experiments it was shown that a fixed length approach reduced the encoding time by a factor of 5-6.

To support the requirement of integer encoding minimality the run-time system must perform a series of checks to determine the size of each integer value. This can be accomplished through successive range checks or successive logical operations on the leading byte of the value. However, regardless of which approach is used, the process is unnecessarily slow. Requiring integers to be encoded in a minimum number of bytes is ill-advised with respect to performance.

5.3.2 Object Identifiers

The encoding and decoding of object identifier values is an unnecessarily inefficient process. Comprised of a series of numeric values, called component values, an object identifier is encoded by representing each component value as a series of seven-bit quantities. These seven-bit quantities are concatenated to form each component. The leading bit of each contents octet is used to demarcate the boundaries of these component values. To further contribute to this inefficiency, the first two components of any object are handled as a special case. Since the value of the first component is restricted to the range 0..2, the encoding of the first two components may be represented using the equation: $40(X) + Y$ where X denotes the value of the first component and Y denotes the value of the second. This requires that the runtime routine that performs this encoding and decoding must use its knowledge of the object identifier tree structure to determine the values of X and Y. The application of this knowledge is expensive.

The use of seven-bit quantities is not desirable since bit masking or arithmetic shifting is always necessary to isolate the value. Furthermore, it is not clear whether a savings of one octet warrants the computationally expensive combination of the first two component values.

5.4 Explicit Tagging

From a philosophical perspective the concept of explicit tagging seems erroneous; it thrusts the responsibility of preventing ambiguity onto the user. It is certainly possible to establish a standard, canonical ordering of the type definitions within any module and to determine tag values from this ordering. Consequently, a compiler could potentially generate these tags and assume this responsibility instead of the user. As long as the generated tags are predictable, economical, and unique, the users needs would be met. For example, a simple top down, left to right sequential numbering scheme would fulfill these three requirements.

If such a sequential tagging generation algorithm were adopted, tag values would not be reusable in the case of mutually exclusive contexts. Therefore, the point at which extended tag values are necessary might arrive sooner than before and would cause the average length of an encoding to increase. However, this point would depend on the extent of the mutually exclusive contexts: note that the tag class values would no longer be required under this new scheme and, therefore, the capacity of the tag id field could be extended from 0..30 to 0..126.

Clearly it is more desirable to have these tags generated in an automated manner since the issue of ambiguity can be subtle and error-prone.

5.5 Sets

The only difference between the ASN.1 sequence type and the ASN.1 set type is that the order of elements within a set is not considered significant. Therefore, opting to define a data type as a set rather than a sequence is less restrictive. There is an intuitive tendency to equate restrictiveness with inefficiency; after all, removing this restriction appears to allow the elements to be reordered during transfer if this presents itself as a more efficient alternative. However, this freedom is not more efficient. In fact the decoding of a set value is far less efficient than a sequence due to this unpredictable ordering and, ironically, it is extremely unlikely that the order that these elements are received will ever differ from the order that appears in the original definition.[22]

The elements of a set value are decoding by a cycle of states within the decoding finite state machine. This cycle is executed until it is determined that the end of the encoding has been

22. The Session Layer does not provide the capability of reordering portions of a single PDU. It is therefore the exclusive responsibility of the ASN.1 compiler to perform this reordering. Yet, it is doubtful that circumstances exist where this would be desirable.

reached. As each element is encountered a boolean flag within the decoding state table, *matched*, is checked and set to indicate that this decoding has occurred. After the appropriate runtime routine performs the actual decoding, a check is made to determine if the end of the encoding has been reached. If this check succeeds, then the *matched* flag of each element must be re-checked in the state table to ensure that all the element values which were not marked as optional or had not been assigned a default value have been represented within the encoding. If all of these checks are successful the decoding terminates successfully.

In contrast, the decoding of a sequence value is a far less time consuming activity. Since the order of elements is significant, decoding is simply a matter of checking each tag as it is encountered to ensure that it matches that which is expected. If this tag check ever fails, the decoding is terminated as a failure. Note that the end of the encoding does not require special processing and there is no need for the *matched* flag to be set or checked.

The inclusion of set types in ISO 8824 appears esoteric and predicated on the need for completeness. Their use within an actual implementation can be deceptive where efficiency is concerned.

5.6 Macros

The Macro Notation enables a user to alter the grammar of the ASN.1 language "on the fly". As such, the existence of macros makes developing a conformant implementation inordinately difficult. Although certain programming languages are capable of solving this class of problem,[23] these languages do not possess the efficiency to make their use advisable in a network implementation. Hence, the current definition of macros poses an obstacle.

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23. programming languages like Icon or LISP

Philosophically, the presence of a macro notation is inappropriate. As a descriptive mechanism that defines the informational content of an application protocol, one of ASN.1's most valuable benefits is the concise and accurate means of *human* communication that it represents. In this respect, it is critical that its form remain standard. This enables ASN.1 to effectively bridge the gap between the precise communication of computers and the imprecise communication of human beings.

With the use of macros, the ASN.1 language can assume an amorphic form that is determined by the personal tastes of the ASN.1 writer. This can only serve to reduce the overall quality of the notation itself.

6. Conclusions

From the development and application of an ASN.1 and BER implementation, it is clear that these two standards are fully capable of providing the data representation commonality necessary to interconnect disparate host environments. To this extent ASN.1 and BER are successful, that is, they achieve their intended objective by solving the problem that motivated their development. However, a meaningful evaluation of these standards must go beyond this issue and determine the degree to which they have succeeded. Three characteristics form the context that makes this determination possible: clarity, ease of implementation, and efficiency.

6.1 Clarity

Clarity is an important aspect of any standard; it reflects the quality of a standard's design and it indicates the degree to which the objectives of the standard have been recognized and achieved. The level of clarity promoted by a standard partially determines the effectiveness of its application. If the users of a particular standard do not possess a clear understanding of how the standard is to be applied, the standard will most likely fail. In general, most of the features of ASN.1 and BER are well founded and explicit with regard to their purpose. In this respect, ASN.1 and BER present a relatively clear picture of their proper application and therefore achieve a satisfactory degree of clarity. However, there are three areas that still require improvement: sets, explicit tagging, and ambiguity.

It appears unlikely that the reordering of elements within an ASN.1 set type will ever occur.

Thus, the inclusion of set types within ISO 8824, and their proper use, is unclear. This nebulous feature represents an efficiency ambuscade since the decoding of a set value requires far more computational effort than that of a sequence. Surprises of this nature are always unwelcome. The ASN.1 standard should either make the inefficiency of decoding a set type explicit, or restructure its description of the conditions under which a set type should be used in preference to a sequence. Annex E of ISO 8824 states that:

> Use a set type to model a collection of variables whose number is known and modest and whose order is insignificant.

A more appropriate description would be:

> Use a set type to model a collection of variables whose number is known and modest and where the potential for the reordering of these variables is known to exist.

ASN.1 thrusts the onus of nonambiguous definitions onto the user through its explicit tagging capability. However, since the concept of *ambiguity* is not well-defined in ISO 8824 (see section 5.1), explicit tagging represents a philosophical inadequacy of ISO 8824 and potential point of confusion. The circumstances that determine when a given definition is ambiguous are numerous and subtle. Even ASN.1 experts, such as those individuals who developed FTAM, are susceptible to mistakes when it comes to the proper use of explicit tags. This makes the use of ASN.1 error-prone and suggests that, as a language, it is not user-friendly. The unwillingness of ASN.1 to confront this issue detracts from its clarity and opens the door for improper use.

6.2 Ease of Implementation

Most language purists will disagree with the position that the anticipated difficulty of developing an implementation should influence the design of a language. Yet, programming languages like FP and Ada serve as reminders that undesirable consequences can occur when

designers are insensitive to the needs of the implementors. To ASN.1 and BER, the ease with which an implementation can be developed is clearly relevant when evaluating their potential success. The macro notation and the lack of support for library management indicate that ASN.1 has not yet achieved its objective of processability.

The ASN.1 macro notation represents an unimplementable "feature" that is currently the most controversial aspect of the standard. Although there is an overwhelming consensus that the presence of macros is undesirable, their use within existing application protocols makes their removal from ISO 8824 difficult. Most of the current macro notation usage centers around creating a parameterized type capability within ASN.1. In recognition of this fact, work is currently underway to develop a parameterized (generic) type that may be offered as an alternative to macros. If successful, the current usages could be converted and the macro notation would disappear.

The inadequate support for library management within the ASN.1 standard also makes the implementation of a compiler difficult in specific cases. For example, it is unclear how the processing of mutually dependent modules can be achieved, if at all. The establishment of a linear elaboration concept would rectify this problem. The vague disposition of the useful types also suggests that a formal approach to library management is needed. The definition of the useful types as a predefined module would simplify their implementation by enabling them to be processed as external type references.

6.3 Efficiency

The most recurring concern relating to a network design, especially OSI, is the efficiency of its implementation. For the most part, the computational expense of encoding and decoding appears to be relatively moderate. However, without the means to compare and contrast the use

of ASN.1 and BER to other mechanisms, it is hard to develop a conclusive perspective of just how fast (or slow) this process is. In any regard, three aspects of ISO 8824 and ISO 8825 are problematic: ambiguity, the minimality of integer encodings, and the encoding of Object Identifier values.

The ill-defined concept of *ambiguity* within ISO 8824 represents a potential problem for any implementation. If tag look-ahead is required to disambiguate an encoding, then the complexity of the logic required to decode a transfer syntax increases dramatically. Under these circumstances, an ASN.1 compiler must generate an LR(k) implementation which causes the efficiency of the decoding process to degrade severely. At the present time, the X3T2 working group of the United States is aware of this problem and is taking action to correct it.

Although the encoding and decoding of integers and object identifiers is not overly difficult, their implementation is unnecessarily slow. In these two instances, the design of the Basic Encoding Rules has favored generality at the expense of efficiency. To the ASN.1 writer, a more flexible approach would be desirable. The ability to select a fixed encoding policy versus a minimal encoding policy would enable protocol developers to tailor their designs accordingly. Only those protocols with a need for encoding minimality would be required to incur the expense associated with the implementation of this feature.

6.4 Contributions

This thesis provides three contributions to the field of Computer Science: it offers a tutorial on ASN.1 and BER, it brings to light several problems associated with these two standards while proposing solutions to these problems, and it lends insight into how an automated implementation of ASN.1 and BER may be realized.

6.4.1 Tutorial

ASN.1 and BER are complex and emerging standards. The only published documentation currently available is the text of the standards. As with most international standards, this text is difficult to read and lacks clear, illustrative explanations. Chapter three of this thesis is a more readable tutorial intended for the practicing engineer and scientist.

6.4.2 Problems and Solutions

Three problems cited within this thesis: the inefficiency of sets, the lack of a formal approach to library management issues and the ill-defined concept of *ambiguity*, were presented to the members of the X3T2[24] working group in July 1989. The members of X3T2 acknowledged that these problems were valid and requested that the author draft a *technical contribution* that proposes viable solutions. This technical contribution is currently being developed and is scheduled to be presented at the international level in October 1989.

6.4.3 Implementation Insights

Along with providing an opportunity to actively participate in the improvement of both standards, the primary contribution of this thesis is the insights it offers into the proper design of an automated implementation of ASN.1 and BER. These insights are summarized below:

1. The LR(*0*) interpretation of *ambiguity* appears to be correct and allows for a finite state machine implementation to be used in the decoding process. This is clearly desirable in that a finite state machine solution offers greater structure, increases the readability of the

24. X3T2 is a committee of the American National Standards Institute that represents the interests of the United States for all communication standards pertaining to the area of data interchange. As such, X3T2 is partially responsible for determining and controlling the content of ISO 8824 and ISO 8825.

generated code and yields an efficient implementation.

2. Partitioning the encoding logic into two phases, the length calculation phase and the runtime encoding phase, is necessary for the compiler to allocate an encoding buffer of the appropriate size before the actual encoding commences. Moreover, prior knowledge of these length values allows the short and long forms of the length octet encodings to be used whenever possible. This is, in many cases, preferable to the indefinite form. For those data types which require that the end of an encoding be known in advance (i.e., set, set-of, and sequence-of), the indefinite form is far less efficient; it requires that the EOC delimiter be located before the decoding can begin.

3. It is appropriate that the compiler generate PDU declarations for the Application layer. This ensures that the encoding and decoding logic will always be consistent with the actual PDU representations. Furthermore, the representation of an APDU as a single variant record allows only one set of decode and encode routines to be generated. Therefore, the caller of the decoding function does not have to know which type is expected at any given time.

6.5 An Overall Assessment

It is clear that ASN.1 and BER represent a viable means of solving the data representation problem of heterogeneous networks. Yet, these standards still require a substantial amount of improvement if their application is to be automated. Considering the youthfulness of ASN.1 and BER, there is hope that many of the problems stated within this thesis can be corrected before the application of these standards becomes too pervasive. The opportunity for positive changes to be made to both ASN.1 and BER still exists.

APPENDIX A

```
#include "string.h"
#include "runtime.h"
#include "Wimp.h"

#define UNKNOWN_LENGTH 0
#define NULL 0
#define tag_matches ((typlen.c == Wimp_fsm[state].type.c) &&
                     (typlen.f == Wimp_fsm[state].type.f) &&
                     (typlen.id == Wimp_fsm[state].type.id))

type_length Date_typlens[] = {
   {universal, primitive, ia5_str, 0, UNKNOWN_LENGTH}
};

type_length Result_typlens[] = {
   {universal, primitive, integer, 0, UNKNOWN_LENGTH}
};

type_length Request_typlens[] = {
   {universal, constructed, sequence, 0, UNKNOWN_LENGTH},
   {universal, primitive, ia5_str, 0, UNKNOWN_LENGTH},
   {universal, primitive, ia5_str, 0, UNKNOWN_LENGTH},
   {universal, primitive, ia5_str, 0, UNKNOWN_LENGTH}
};

struct decode_state {
   struct {
      class c;
      form f;
      int id
   } type;
   int match_state;
   int diff_state;
   int end_state;
   boolean matched
} Wimp_fsm[] = {
   {{universal, primitive, 22}, -1, 1, 0, false},
   {{universal, primitive, 2}, -1, 2, 0, false},
   {{universal, constructed, 16}, 3, -2, 0, false},
   {{universal, primitive, 22}, 4, -2, 0, false},
   {{universal, primitive, 22}, 5, -2, 0, false},
   {{universal, primitive, 22}, -1, -2, 0, false},
};

encode_Wimp (decoding, encoding)
             Wimp_apdu *decoding;
```

```
            Wimp_encoding *encoding;
{
   byte *offset;
   int i;

   switch (decoding->which_apdu) {
      case Date:
         Date_typlens[0].length = strlen(decoding->apdu.Date);
         encoding->length = Date_typlens[0].length +
            lenlen(Date_typlens[0].length) + 1;
         encoding->value = (byte *)malloc(encoding->length);
         offset = encoding->value;
         enc_typlen(&offset, &Date_typlens[0]);
         enc_ia5str(&offset, decoding->apdu.Date,
            Date_typlens[0].length);
         break;
      case Result:
         Result_typlens[0].length = int_len(decoding->apdu.Result);
         encoding->length = Result_typlens[0].length +
            lenlen(Result_typlens[0].length) + 1;
         encoding->value = (byte *)malloc(encoding->length);
         offset = encoding->value;
         enc_typlen(&offset, &Result_typlens[0]);
         enc_int(&offset, decoding->apdu.Result);
         break;
      case Request:
         Request_typlens[1].length =
            strlen(decoding->apdu.Request.assignedto);
         Request_typlens[2].length =
            strlen(decoding->apdu.Request._unnamed_1);
         Request_typlens[3].length =
            strlen(decoding->apdu.Request.description);
         Request_typlens[0].length = 0;
         Request_typlens[0].length +=
            Request_typlens[1].length +
            lenlen(Request_typlens[1].length) + 1;
         Request_typlens[0].length +=
            Request_typlens[2].length +
            lenlen(Request_typlens[2].length) + 1;
         Request_typlens[0].length +=
            Request_typlens[3].length +
            lenlen(Request_typlens[3].length) + 1;
         encoding->length = Request_typlens[0].length +
            lenlen(Request_typlens[0].length) + 1;
         encoding->value = (byte *)malloc(encoding->length);
         offset = encoding->value;
         enc_typlen(&offset, &Request_typlens[0]);
         enc_typlen(&offset, &Request_typlens[1]);
         enc_ia5str(&offset, decoding->apdu.Request.assignedto,
```

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```
                Request_typlens[1].length);
            enc_typlen(&offset, &Request_typlens[2]);
            enc_ia5str(&offset, decoding->apdu.Request._unnamed_1,
                Request_typlens[2].length);
            enc_typlen(&offset, &Request_typlens[3]);
            enc_ia5str(&offset, decoding->apdu.Request.description,
                Request_typlens[3].length);
            break;
         default:
            return(FAILURE);
      }
      return(SUCCESS);
}

decode_Wimp (encoding, decoding)
             byte *encoding;
             Wimp_apdu *decoding;
{
   type_length typlen;
   int state = 0;
   byte *tmp, *offset = encoding;
   int i;

   dec_typlen(&offset, &typlen);
   while (1) {
      switch (state) {
         case -2:     /* FAILURE state */
            return(FAILURE);
         case -1:     /* SUCCESS state */
            return(SUCCESS);
         case 0:/* Date */
            if tag_matches {
               decoding->apdu.Date =
                  (char *)dec_ia5str(&offset, typlen.length);
               state = Wimp_fsm[state].match_state;
               decoding->which_apdu = Date;
               dec_typlen(&offset, &typlen); }
            else
               state = Wimp_fsm[state].diff_state;
            break;
         case 1:/* Result */
            if tag_matches {
               decoding->apdu.Result =
                  dec_int(&offset, typlen.length);
               state = Wimp_fsm[state].match_state;
               decoding->which_apdu = Result;
               dec_typlen(&offset, &typlen); }
            else
               state = Wimp_fsm[state].diff_state;
```

```
            break;
         case 2: /* Request */
            if tag_matches {
               state = Wimp_fsm[state].match_state;
               decoding->which_apdu = Request;
               dec_typlen(&offset, &typlen); }
            else
               state = Wimp_fsm[state].diff_state;
            break;
         case 3: /* assignedto */
            if tag_matches {
               decoding->apdu.Request.assignedto =
                  (char *)dec_ia5str(&offset, typlen.length);
               state = Wimp_fsm[state].match_state;
               dec_typlen(&offset, &typlen); }
            else
               state = Wimp_fsm[state].diff_state;
            break;
         case 4: /* Date */
            if tag_matches {
               decoding->apdu.Request._unnamed_1 =
                  (char *)dec_ia5str(&offset, typlen.length);
               state = Wimp_fsm[state].match_state;
               dec_typlen(&offset, &typlen); }
            else
               state = Wimp_fsm[state].diff_state;
            break;
         case 5: /* description */
            if tag_matches {
               decoding->apdu.Request.description =
                  (char *)dec_ia5str(&offset, typlen.length);
               state = Wimp_fsm[state].match_state;
               dec_typlen(&offset, &typlen); }
            else
               state = Wimp_fsm[state].diff_state;
            break;
      }
   }
}
```

APPENDIX B

```
ISO8571-FTAM DEFINITIONS ::= BEGIN

PDU ::= CHOICE {
   FTAM-Regime-PDU,
   File-PDU,
   Bulk-Data-PDU
}

FTAM-Regime-PDU ::= CHOICE {
   [0] IMPLICIT F-INITIALIZE-request,
   [1] IMPLICIT F-INITIALIZE-response,
   [2] IMPLICIT F-TERMINATE-request,
   [3] IMPLICIT F-TERMINATE-response,
   [4] IMPLICIT F-U-ABORT-request,
   [5] IMPLICIT F-P-ABORT-request
}

F-INITIALIZE-request ::= SEQUENCE {
   protocol-id Protocol-Version DEFAULT {
      major {version-1},
      minor revision-1
   },
   presentation-context-management
      [1] IMPLICIT BOOLEAN DEFAULT FALSE,
   service-level Service-Level DEFAULT reliable,
   service-class Service-Class DEFAULT transfer-class,
   functional-units Functional-Units OPTIONAL,
   attribute-groups Attribute-Groups DEFAULT {},
   rollback-availability Rollback-Availability OPTIONAL,
   contents-type-list Contents-Type-List OPTIONAL,
   initiator-identity User-Identity OPTIONAL,
   account Account OPTIONAL,
   filestore-password Password OPTIONAL,
   checkpoint-window [8] IMPLICIT INTEGER DEFAULT 1
}

Protocol-Version ::= [0] IMPLICIT SEQUENCE {
   major [0] IMPLICIT BIT STRING {version-1(0)},
   minor [1] IMPLICIT INTEGER {
      revision-1(1)
   } DEFAULT revision-1
}

Service-Level ::= [2] IMPLICIT INTEGER {
   reliable(0),
   user-correctable(1)
}
```

```
Service-Class ::= [3] IMPLICIT INTEGER {
   transfer-class(0),
   access-class(1),
   management-class(2),
   transfer-and-management-class(3),
   unconstrained-class(4)
}

Functional-Units ::= [4] IMPLICIT BIT STRING {
   read(2),
   write(3),
   file-access(4),
   limited-file-management(5),
   enhanced-file-management(6),
   grouping(7),
   recovery(8),
   restart-data-transfer(9)
}

Attribute-Groups ::= [5] IMPLICIT BIT STRING {
   storage(0),
   security(1),
   private(2)
}

Rollback-Availability ::= [6] IMPLICIT INTEGER {
   no-rollback(0),
   rollback-available(1)
}

Contents-Type-List ::= [7] IMPLICIT SEQUENCE {
   document-types [0] IMPLICIT SEQUENCE OF
      Document-Type-Name,
   constraint-sets-and-abstract-syntaxes [1]
      IMPLICIT SEQUENCE {
         constraint-sets [0]
            IMPLICIT SEQUENCE OF Constraint-Set-Name,
         abstract-syntaxes [1]
            IMPLICIT SEQUENCE OF Abstract-Syntax-Name
      }
}

User-Identity ::= [APPLICATION 4] IMPLICIT IA5String

Account ::= [APPLICATION 5] IMPLICIT IA5String

Password ::= [APPLICATION 6] CHOICE {
   IA5String,
   OCTET STRING
```

```
    }

    Document-Type-Name ::= [APPLICATION 7]
       IMPLICIT OBJECT IDENTIFIER

    Constraint-Set-Name ::= [APPLICATION 8]
       IMPLICIT OBJECT IDENTIFIER

    Abstract-Syntax-Name ::= [APPLICATION 9]
       IMPLICIT OBJECT IDENTIFIER

    F-INITIALIZE-response ::= INTEGER

    F-TERMINATE-request ::= INTEGER

    F-TERMINATE-response ::= INTEGER

    F-U-ABORT-request ::= INTEGER

    F-P-ABORT-request ::= INTEGER

    File-PDU ::= INTEGER

    Bulk-Data-PDU ::= INTEGER

END
```

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