The contextual parsing of natural language

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ABSTRACT

This paper describes a mechanism for parsing natural language input. The mechanism relies on context to resolve ambiguities. This ability is in turn dependent on a functional relation between the parser and the data structure which represents both the knowledge and logic of the subject matter domain. To illustrate this interdependence, the discussion is limited to a single program used to teach anatomy to medical students. However, the same parser has been used for other courses in the medical curriculum.
INTRODUCTION

The Computerized Anatomical Teaching System (CATS) is an interactive computer program used to teach gross anatomy to medical students. CATS contains no prestored questions or answers and does not rely on keyword analysis. It contains: (1) a natural language parser that interprets the meaning of a student's question or answer, (2) an abstract (numeric) representation of anatomical knowledge and logic which it uses to answer or generate questions, and (3) the ability to generate text and compose it into phrases, clauses, sentences, and paragraphs.

The anatomy each first year medical student is required to learn comprises a very large body of knowledge. Because it is a descriptive discipline, anatomy generally has been considered a memory course consisting of learning the names of things together with their functional and spatial relations. All the information that CATS contains can be displayed on approximately 15 typewritten pages. The program can use this small database to answer virtually any question that could be found in an unabridged textbook (1500 pages).

In addition to being able to use these basic relations for deducing more complex ones, CATS also has the ability to discover and articulate meaningful general principles which it offers as "reasons" for its answers to further reduce the need for memorization. It does this for 80 percent of the questions asked. The pedagogic goal of the program is to demonstrate to students the method of reasoning, and reasoning's advantage over rote memorization.

This paper is limited to a description of how the program processes input, with particular emphasis on the use of context in resolving potential ambiguities. A more comprehensive description of the program, including the mechanisms of reasoning and text generation, may be found in Hagamen and Gardy.1 CATS is coded in APL and implemented on both 8086 (IBM PC/AT) and 68000-based microcomputers.

DATA STRUCTURE

To understand the parsing mechanism, it is necessary to know the types of information the program has about the domain in which it operates. The parsing described relies on what we shall call context. This, in turn, depends on the program's anatomical knowledge.

The program has available four types of data: (1) node descriptors, (2) relational matrices, (3) node profiles, and (4) syntactic words.

Node Descriptors

The names of anatomical structures are stored as a list of noun phrases that may be single words or groups of words. Each of these node descriptors also may contain synonyms enclosed within parentheses.

The noun phrases serve two roles. First, they are used by the utility program that automatically generates the vocabulary lists which in turn are used to determine which nodes a student is talking about. Second, they are used when the program is generating the text involved in asking or answering questions.

An example of a node descriptor is: FLEXOR DIGITI MINIMI (FIFTH FINGER LITTLE QUINTI V 5). FLEXOR DIGITI MINIMI would be used when the program is generating a question or reply. However, the program could recognize any combination of words input that uniquely identifies the structure. For example, it could recognize FLEXOR OF THE LITTLE FINGER or FLEXOR DIGITI V.

Relational Matrices

A fact such as the musculocutaneous nerve innervates the biceps is an expression of a functional relation between two anatomical structures (nodes). Within the domain of anatomy there are more than 30 such generic types of relationships, each of which is represented by verbs or verb equivalents.

Relationship information is stored in a series of two-row numeric matrices. For the relationship of innervates (i.e., innervated by, nerve supply of), the node numbers of the structures (nerves) doing the innervating are stored in the first row of the matrix. Node numbers of the structures being innervated (e.g., muscles, viscera, and bones) are stored in the second row. The verb uniquely defines this matrix. Similar matrices exist for each different type of relationship (e.g., origin or insertion of, branches, arterial supply, venous or lymphatic drainage, spatial relations such as anterior/posterior, and distal/proximal).

Node Profile

CATS includes an integer vector that is equal in length to the number of node descriptors and which contains a number to indicate the type of tissue each node represents (e.g., 1 = artery, 2 = bone). This information is called the profile of the node. The program uses this stored information to calculate the "expected profile," which plays an important role in the parsing.
**Syntactic Words**

The program also includes a predefined list of approximately 128 special words or syntactic markers. Each special word has an associated decimal value (called its word type) that reflects the word’s role within our rules of discourse. These tagged words include interrogative pronouns, helping verbs, anatomical “verbs,” prepositions, pronouns, articles, conjunctions, and punctuation.

These syntactic words serve three main functions. First, they help in breaking a sentence into functionally useful parts or phrases. Second, the anatomical verbs direct the program to the proper numeric matrix. Third, combinations of interrogative pronouns and helping verbs define the nature of a question—whether it is asking “what is,” “why,” “where,” or if something is true or false.

**VOCABULARY LISTS, WORD TYPES, AND NODE POINTERS**

After the previously defined data has been entered, a utility function scans the list of node descriptors. It takes the first occurrence of each such naturally appearing word and stores it in a vocabulary list. The utility function also records the node numbers (relative positions of the noun phrases) in which each occurrence of the word is found.

Some words in the special word list may also be found in node descriptors. This is particularly true of the anatomical verbs. The positional numbers of the nodes to which these words point is also recorded. The vocabulary lists therefore include both the special words and those that occur only as part of node descriptors.

For every word in the vocabulary there are three types of data: the word itself, its numeric word type, and the list of nodes to which each word points. All the special words have a decimal word type which, as stated, defines its syntactic role. Words found only in the node descriptor list are given a zero word type. All words found in the node descriptor list have an associated vector of node pointers. For those syntactic words that do not appear in the list of anatomical names, the pointer vector is empty.

The total vocabulary is subdivided into 27 smaller lists according to the initial character in each word. Thus we have an A-vocabulary, a B-vocabulary, and so forth. Punctuation and numbers form the twenty-seventh list. This subdivision into lists slightly reduces search time.

**PARSING OVERVIEW**

Parsing proceeds from left to right, one word at a time. The first character of each word determines which vocabulary must be searched. The location of a word in the vocabulary also results in retrieval of its word type and the node descriptors, if any, in which that word occurs.

The goal of the parsing is to obtain the information necessary to understand a student’s question. Thus, parsing includes four features. First, it determines which nodes (anatomical structures) are being asked about. Since several of the nodes in question may occur in the same input string, individual noun phrases are isolated. Second, it identifies the nature of the relationship specified between the nodes. This involves analyzing potential verb constructions, including predicate adjectives and predicate nominatives. Third, it determines whether the domain of the verb is restricted by the presence of adverbs and prepositional phrases. Fourth, it identifies the combinations of interrogative pronouns and helping verbs which serve to define the nature of the question, and this in turn dictates the form of the answer.

A question such as: WHAT ARE THE ACTIONS OF THE LONG HEAD OF THE BICEPS ON THE FOREARM? would be parsed as follows:

<table>
<thead>
<tr>
<th>Word Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHAT ARE</td>
<td>1.7</td>
</tr>
<tr>
<td>THE ACTIONS OF</td>
<td>3.0</td>
</tr>
<tr>
<td>THE LONG HEAD</td>
<td>6.2</td>
</tr>
<tr>
<td>OF THE BICEPS</td>
<td>5.7</td>
</tr>
<tr>
<td>ON THE FOREARM</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>9.0</td>
</tr>
</tbody>
</table>

Those words found in the syntactic word list are underlined so that a user can identify them. The numeric value (word type) assigned to each word is also shown. The first two words are interrogatives (the floor of their word types is 1), and their combination specifies this as a “what-type” question. The second row contains the relational phrase. In this example, the relational phrase is a predicate nominative. The third row is a noun phrase which indicates the anatomical entity (muscle) about which the student is asking. The fourth row is the prepositional phrase which limits the various actions asked about to those that move the forearm.

There are two types of relational words (verbals). (1) Some words define specific functions or relations. Examples include: INNERVATES, IS A BRANCH OF, and FLEXES. These words are assigned a word type with a floor of 2 (indicating that it is such a specific verbal). The relational matrix to which it points is encoded in the mantissa of its word type. (2) Other words indicate more generic relationships and have a word type with a floor of 6. Actions, for example, include such specific movements as flexion, extension, abduction, adduction, supination, pronation, internal and external rotation. The mantissa of the word type of these generic verbals points to a matrix which contains the numeric values of the specific verbals involved.

Node descriptors are separated by words that flag the beginning of a noun phrase such as determiners or, importantly, by word types (punctuation and conjunctions) that signal the end of a previous noun phrase as in THE BICEPS and BRACHIALIS AND CORACOBRACHIALIS. Prepositions have a word type with a floor of 5. The specific type of preposition is encoded in the mantissa. In this regard, OF represents a special case. When OF separates two non-verbal noun phrases (THE LONG HEAD OF THE BICEPS), the two phrases are treated as one to define the node descriptor. Any preposition that either immediately follows a verbal (ACTIONS OF, BRANCHES INTO), or does not immediately precede an article (OF WHAT IS THE RADIAL NERVE A BRANCH?), is considered part of the verb phrase.
VERB ANALYSIS

As stated, the verbs represent the nature of the relationship. However, many of these relations are expressed as adjectives or nominatives, rather than as verbs. At one time a word may be used to express a relationship, but at another time the same word may be used as a node descriptor. Fifty percent of the potential verbals exhibit this dual role. The program also must determine which row of the pointer matrix to search for the nodes, depending on their relation to the verb that is identified.

Identifying The Functional Verb

Potential verbs are flagged by having a word type with a floor of 2 or 6. Resolution is required when there is more than one such word in the input. The first test is whether the tagged word has any associated node pointers (can it be part of a node descriptor?). If it has no node associations, it must be a verb. If the ambiguity remains, two additional tests may be done. (1) If the word is one of the adjectivals (ANTERIOR, POSTERIOR, LATERAL, MEDIAL, INFERIOR, SUPERIOR, DEEP, SUPERFICIAL, DISTAL, PROXIMAL), it must be followed by TO or it must be the terminal word in order to be acting as a verb. (2) If it is an ambiguous nominative (BRANCH, PART), it must be preceded by a determiner (A, AN, THE), in order to be a verb. This takes advantage of the fact that these words are always preceded by an adjective when they occur in a node descriptor (CLAVICULAR BRANCH OF, SECOND PART OF). Once the active verb has been identified, the word types of the competing verbals are converted to zero, and they become available to the parser as noun phrase constituents.

Determining The Row Numbers

The verbals encountered by the program include transitive verbs, intransitive verbs, predicate nominatives, and predicate adjectives. For this reason it is not particularly useful to think in terms of subject, verb, and object. However, it should be apparent from the nature of the relational matrices that all questions are dyadic—they involve a relation between two things (or groups of things). One of these is stored in the first row of the matrix and the other in the second row. It is the program's task to determine which is which.

Some questions have the general form: WHAT IS THE ORIGIN OF THE BICEPS? or WHAT IS THE CORACOID PROCESS THE ORIGIN OF? Clearly one of the two arguments (nodes) is given in the question. The other is unknown but is tokenized by the word holding function of WHAT. This unknown represents the answer which the program must fill in. In true or false questions, both arguments are given: IS THE CORACOID PROCESS THE ORIGIN OF THE BICEPS? However, when attempting to answer this type of question, the program temporarily masks the left argument, processes the remainder as a what-type question, and then compares its answer with the masked node. In both situations the program needs to know which row contains the given node and which contains the answer.

Determining which row contains the node and which contains the answer is performed by a simple APL function. A brief introductory discussion may help in evaluating the features of the APL function. First, all verbals, except adjectives, have an infinitive verb form. For example, ORIGINATE is the infinitive form of ORIGIN OF and INNERVATE is the verb infinitive for INNERVATED BY. The node that would be considered the subject of the verb infinitive is stored in row 1. Second, the adjectivals occur in pairs of logical opposites (e.g., ANTERIOR—POSTERIOR, MEDIAL—LATERAL). These have no verb infinitive equivalents. One half of each pair has a positive word type; its opposite is the negative of the same word type. If you think of a declarative sentence (e.g., THE AXILLARY ARTERY IS ANTERIOR TO THE POSTERIOR CORD.), the left argument (AXILLARY ARTERY) of a positive adjectival (IS ANTERIOR TO) is in row 1, and the right argument (POSTERIOR CORD) is in row 2. If the adjectival has a negative word type (IS POSTERIOR TO), the relationship is reversed. In this way the absolute value of these word types performs both roles—there are no negative values in the relational matrices.

The APL function that performs this task returns a value (1 or 2) to indicate the row number where the answer, as defined above, is located. The process involves several steps and conditional tests. (1) If the verb is followed by a noun phrase, the answer is assumed to be in row 2; otherwise it is in row 1. (2) This decision is reversed if the verb either has a negative word type (IS POSTERIOR TO) or is the nominative form of an intransitive verb (ORIGIN OF, INSERTION OF, PART OF, BRANCH OF). The reason for this depends on the transivity of the verb. In the nominative form of a transitive verb (THE MUSCULOCUTANEOUS NERVE IS THE INNERVATION OF THE BICEPS), the structure doing the innervating appears before the verb. When the verb is intransitive (THE MUSCULOCUTANEOUS NERVE IS A BRANCH OF THE MEDIAL CORD), the structure doing the branching follows the verb. (3) If the question contains a possessive, as indicated by the word types, the result is reversed again. ITS INNERVATION is equivalent to INNERVATION OF IT. (4) Passive voice, when present, causes an additional reversal. (5) A final reversal occurs if the verb is immediately followed by certain prepositions which have not already been factored in (BRANCH FROM versus BRANCH INTO). All decisions are based on the numeric (word type) form of the question which already exists.

CONTEXTUAL UNDERSTANDING

If a system justifies the term intelligent, it should not impose any special—even well accepted—rules of grammar or syntax on a user. The program should be as understanding and flexible as its human counterpart. Therefore, the program must be able to recognize and use the context of a dialogue. The ways in which this program uses context to help its understanding are illustrated in the following sections by specific examples.
Role of Individual Words

Given the question WHERE DOES THE EXTENSOR CARPI RADIALIS BREVIS ORIGI­NATE?, the program extracts a four-word noun phrase, EXTENSOR CARPI RADIALIS BREVIS. Each word (with a word type of zero) occurs as part of a number of different node descriptors. The node numbers associated with each word are shown:

EXTENSOR 41 69 70 71 72 73 74 75 76 324 325 326 327 328
CARPI 69 70 71 87 88 315
RADIALIS 33 69 70 87 234
BREVIS 2 69 75 97 197

The only node number that all four words share in common is 69 which, not surprisingly, is the EXTENSOR CARPI RADIALIS BREVIS. The first word in the sequence, no matter what it happens to be, activates (brings to mind) a number of associations. Each succeeding word, by a process of logical “and-ing,” makes the meaning more specific. Thus, on the simplest level, the words in the noun phrase provide the context. Indeed, noun phrases have evolved as a part of language to eliminate ambiguity.

Role of The Verb-Pronoun Reference

Pronoun reference is achieved by storing the node numbers for the subject and objects (or answers) to the previous question. However, because the discussion usually involves a relation between two or more nodes, ambiguity is introduced. To which should the pronoun refer?

Q: WHAT IS THE INNERVATION OF THE BICEPS?
A: THE MUSCULOCUTANEOUS NERVE.
Q: WHAT IS ITS ACTION?
A: IT FLEXES THE SHOULDER AND ELBOW AND SUPINATES THE FOREARM.

In this example, the pronoun is interpreted to be referring to the subject of the previous question, not to the answer. However, if the second question had been WHAT ELSE DOES IT INNERVATE?, both we and the program would have coupled it to the previous answer: THE MUSCULOCUTANEOUS NERVE. This is not dependent on grammatical rules. Rather, it is based on the semantic rule that nerves, not muscles, innervate things.

In this situation the verb provides the context. Every node has an associated profile (number) that indicates the type of structure. When it searches the relational matrix representing the verb INNERVATES, it determines that all the node numbers in row 1 (representing the structure doing the innervating) have a profile of 6, which means they are nerves. We call this the “expected profile.” BICEPS has a profile of 5 (muscle) and MUSCULOCUTANEOUS NERVE has a profile of 6 (nerve). For this reason, the latter node is assigned to the pronoun.

Role of the Verb-Partial Phrases

The profile and expected profiles have generic applications. In this regard consider the following question, which has nothing to do with pronoun reference: WHAT ANASTOMOSES WOULD DEVELOP FOLLOWING AN OCCLUSION BETWEEN THE SECOND AND THIRD PARTS OF THE AXILLARY? This is a very natural way to ask this question. The program extracts more information than was explicitly provided. It knows, for example, that the question refers to the AXILLARY ARTERY, as opposed to the AXILLARY NERVE or AXILLARY VEIN because it is the only interpretation that would agree with the expected profile. Similar logic indicates that SECOND refers to SECOND PART OF THE AXILLARY ARTERY rather than the SECOND RIB or SECOND DORSAL INTEROSSEOUS.

After discarding the three non-zero word types (OF THE ?), the noun phrase contains three words: THIRD PARTS AXILLARY. The APL function that takes over the selection process from this point is called GNODE. Each word in the vocabulary that has a zero word type has an associated vector of numbers indicating all the node descriptors in which that word was found. The right argument of GNODE is all of these node numbers for each of the (three) words in this phrase. For this particular phrase there are 17 such numbers. A list of the numbers, together with the complete form of each node descriptor, follows:

153 LOWER ⅔ OF ANTERIOR SURFACE OF HUMERUS (TWO THIRDS)
155 LUMBRICAL TO DIGIT 3 (FINGER THIRD)
294 THIRD PART OF AXILLARY ARTERY (3)
84 FIRST PART OF AXILLARY ARTERY (1)
251 SECOND PART OF AXILLARY ARTERY (2)
294 THIRD PART OF AXILLARY ARTERY (3)
19 AXILLA
20 AXILLARY ARTERY
21 AXILLARY GROUP OF MUSCLES
22 AXILLARY NERVE
23 AXILLARY VEIN
66 DORSAL SURFACE OF AXILLARY BORDER OF SCAPULA
84 FIRST PART OF AXILLARY ARTERY (1)
228 QUADRANGULAR SPACE OF AXILLA
251 SECOND PART OF AXILLARY ARTERY (2)
294 THIRD PART OF AXILLARY ARTERY (3)
307 TRIANGULAR SPACE OF AXILLA

Notice that the first three node descriptors contain the word THIRD; the next three include PART; and the remaining eleven all represent AXILLA.-

GNODE next eliminates all the elements of the list that do not have a node profile corresponding to ARTERY. The reason for this is that the verb in this case carries an expected profile of ARTERY—only arteries anastomose in the program’s experience. The resulting shortened list follows (note that they all contain the word ARTERY, even though this was not included in the user’s question):
Notice the redundancy. Node 294 occurs three times, 84 and 251 each appear twice, and 20 is present only once. This means that node 294 is the closest match and is selected as the output of GNODE.

The program now looks at the next phrase (SECOND). The right argument for GNODE contains eight node numbers. There is no redundancy because there is only one word in the phrase.

Despite the fact that GNODE must determine that SECOND uniquely defines SECOND PART OF THE AXILLARY ARTERY in the context of the total question, the process actually is simpler than before. The only node number in the list that happens to have a profile number corresponding to ARTERY is 251.

Role of Complementary Phrases

As you and I read the original question, we would also realize that SECOND referred to SECOND PART OF THE AXILLARY ARTERY by an entirely different means. We would probably assume that the two phrases were parallel and that the missing parts of the partial phrase were to be found in the following one. The program also uses this logic when necessary.

Consider the question: WHAT ARE THE ACTIONS OF THE BICEPS? Processing begins with the second of the two noun phrases resulting from the parsing (THIRD LUMBRICALS). The vector of node numbers presented to GNODE is shown. Node 155 appears twice, indicating that it contains both words.

Adjectives Restricting The Context

Some verbals (relational words) are generic in that they each refer to several specific subtypes. Attachments include both origins and insertions. Actions refer, for example, to flexion, extension, abduction, adduction, pronation, supination, and external and internal rotation. Relations include all the logical opposites described in the VERB ANALYSIS section. Anterior–posterior and medial–lateral are two examples.

If the question is WHAT ARE THE RELATIONS OF THE WRIST?, the program will list the anterior relations and then the posterior relations because anterior relations and posterior relations are different “verbs.” However, if the question is WHAT ARE THE ANTERIOR RELATIONS OF THE WRIST?, the program will list only the anterior relations. Any logical variation of this question produces the expected results. For example, WHAT ARE THE ANTERIOR AND POSTERIOR RELATIONS OF THE WRIST? produces both answers. Effectively, this restricts the meaning of the predicate nominative (ARE THE RELATIONS OF) to whatever adjectives modify RELATIONS. If there are no modifiers, all relations are listed.

Prepositional Phrases Restricting The Context

The domain of relational verbs may also be limited by prepositional phrases. Consider the following sequence:

Q: WHAT ARE ITS ACTIONS ON THE FOREARM? A: IT SUPINATES THE FOREARM.

WHAT ARE THE ACTIONS OF THE BICEPS? produces three verb-object pairings (flex–shoulder, flex–elbow,
and supinate–forearm). The prepositional phrase eliminated those actions on objects not included in the prepositional phrase (ON THE FOREARM).

**Contextual Interpretation of Spelling Errors**

The phrase EXTENSOR ACRPI RADIALIS BREVIS contains a single typographical error—the reversal of CA in CARPI. The program never becomes aware of this mistake, because the three remaining words uniquely define the intended node. Because ACRPI is not in the vocabulary it cannot have any node pointers.

If two words are misspelled (EXTENSOR ACRPI RDIALIS BREVIS), the ambiguity in this case would be between two nodes:

- 69 EXTENSOR CARPI RADIALIS BREVIS (HAND SHORT)
- 75 EXTENSOR POLlicis BREVIS (SHORT THUMB)

However, because the context has narrowed the ambiguity to these two nodes, the misspelled words (those with no node pointers) are compared only to the words in these two node descriptors. This is done by means of the closest character match, which is essentially an APL primitive function.

**DISCUSSION AND SUMMARY**

In a computational sense, the parser we have described is much simpler than previous models. It does not backtrack, look ahead, or consider parallel strategies. Despite this, it meets all our needs. The program could interpret any input we could understand—including ungrammatical but meaningful constructions.

Certainly the task is simplified by the limited subject matter domain. On the other hand, anyone who has seen a 1500 page textbook of gross anatomy could hardly call CATS a trivial application. The ability to identify nodes despite the ambiguities in all the examples included in this paper, and to do so in a fraction of a second, represents an important facility for natural language comprehension.

One explanation for the simplicity is that the parser is goal directed. It does not look for grammatical rules—any more than people do. Rather, it looks for the specific information needed to understand what is intended by a student. This includes: (1) determining the topics (nodes) a student is talking about which, in turn, involves isolating individual noun phrases; (2) looking for verbs (relations) that, if present, limit what is being asked about the topics; (3) recognizing words and phrases that may restrict the domain of the verbs; and (4) using interrogatives and helping verbs to determine the nature of the question. Minimal syntactic clues are used for these purposes.

The importance of storing the noun phrases (names of things) that define the subject matter domain rather than individual words cannot be overly emphasized. It seems intuitively apparent that people use the same technique; we think in terms of names of things and use words in various combinations to access these names. The utility of this in resolving typographical errors and other ambiguities is illustrated in this paper.

Perhaps the most important feature of the parser is the functional way in which it interfaces with the program’s knowledge of anatomy (the relational matrices). The expected profile, which plays an essential role in defining the context, is dynamic; it reflects the program’s own anatomical knowledge.

The two most important tools in resolving ambiguities—the pointers from vocabulary words to specific nodes and the expected profile—are calculated by the program; they are not entered by a programmer. This is labor saving and it ensures that the data is accurate and current as new information is added.

The algorithmic generation of text, which is not described in this paper, also utilizes the program’s anatomical knowledge. The raw answers are columns of the relational matrices. These consist of node numbers and verb values that directly represent noun phrases and verb phrases. The program also knows the purpose of the question and takes this into account when phrasing the response. For the simplest questions, formatting the answer may involve little more than retrieving the appropriate noun phrase or verb phrase. When multiple nodes and pointers are involved, proper sentence construction requires combining nodes into logical groups (phrases) according to their profile types and adjective values and into clauses according to the associated verbs.

CATS is an example of “intelligent” CAL. In addition to its ability to demonstrate the advantages of reasoning over memorization and its ability to discover and express general principles, another advantage over more conventional computer mediated tutorials is that a single teacher can enter the information necessary to cover an entire discipline in a reasonable period of time. This same technique has been applied to medical diagnosis (MEDCAT), and we plan to extend it to other subjects in the medical curriculum.

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Rapid advances in the development of computer architectures are revolutionizing scientific research and technological development. In the last few years, an unprecedented expansion has taken place in the boundaries of computer architectures directed towards parallel processing and high execution rates. These sessions examine the impact this expansion is having on the computer industry—specifically, the number of distinctive designs available commercially and the effects on science and technology.