

cess. This is best done unobtrusively through the skillful use of probing and action plans.

When the assignment is first made to build a curriculum, the writer should be ready with probes concerning job behaviors, needs assessment, and objectives. After a period of time the client should come to expect certain questions and gradually develop an awareness of the developmental steps involved in good training design. This is the groundwork for future negotiations to conduct a full-blown needs assessment.

After an assignment gets underway, the curriculum writer should map out an action plan detailing the step-by-step procedures required to produce the training program. This can consist of fitting the client's request into a model for training design and explaining the tasks involved and possible time allotments for each task. The action plan should be sent to the client and he should be kept abreast of the work as it

proceeds. Through this process, the client will become more familiar with the steps of training design and will be more understanding of the inputs and time required to produce a good training program.

The suggestions offered in this article can never take the place of systematic job analysis, needs assessment, and evaluation. However, not every trainer and curriculum writer can control the total training development process. They have to work within the constraints of the organization, effecting changes where they can.

ACKNOWLEDGMENT

This article is based on the Critical Events Model of Dr. Leonard Nadler, George Washington Univ., Washington, DC (see Fig. 1).

The Rules of Language

MORRIS HALLE

Abstract—We all share some basic information about our native language but we are not conscious of ever having learned or worked out the principles involved. For example, we “know” upon hearing them that certain sound sequences could not be words in our language although we have never been taught the principles that govern English word structure. In addition, we possess information about language which could not plausibly be attributed to learning. This unlearned knowledge as well as the knowledge acquired without overt teaching is attributed to innate mechanisms—the consequence of the genetic endowment that differentiates between humans and other species.

THE sounds that we hear when spoken to and that we emit when speaking are produced by complex gymnastics executed by our lips, tongue, velum, larynx, and lungs. The activities of these independent anatomical structures are coordinated with a precision that should be the envy of the most highly trained ballet dancer; yet this truly remarkable exercise is performed at the drop of a hat by even the clumsiest person. In contrast, even the most adroit primates have never been able to master it, despite intensive training. These facts suggest that the ability to speak is linked to our genetic endowment, that it is one of the aspects in which humans differ from all other mammals.

The gymnastic feats involved in speaking are clearly not the whole story. Speech is not just some noise that humans are capable of emitting; it is a noise that is produced to convey

meaning. And how speech conveys meaning is surely one of the great puzzles that has intrigued thinkers for centuries.

Once the question of meaning is introduced, it is clear that we have to go beyond an analysis of vocal organ movements and of the acoustic signals these movements elicit. Such an analysis can tell us how the sounds of English differ from those of Finnish or Kwakiutl, but it cannot tell us why a sequence of sounds uttered by a speaker of English means something to us, whereas a sequence of sounds uttered by a speaker of Kwakiutl, or Finnish, usually means nothing. If we ask ourselves why most of us are able to understand a speaker of English but not a speaker of Finnish or Kwakiutl, the trivially obvious answer is that we know English but we don't know Finnish or Kwakiutl. But that answer leads naturally to a question with a much less obvious answer: What is the character of the specific knowledge that speakers of a particular language possess through which they are able to understand one another? Although not all linguists might choose to formulate it precisely in this fashion, this question has always been central to the science of linguistics.

WORDS: TO SAY AND TO HEAR

A striking fact about all speech is that all speakers—no matter in what language—are sure that they produce words, and all hearers are certain that they perceive utterances as sequences of words. When we pay attention to our own speech, we observe at once that we do not normally break up our utterances into words; rather, we run words together without intervening pauses. One can readily convince oneself of this fact by reading a text in a way so — as — to — pause — after — every — word and observing that the result is highly unnatural.

The acoustical speech signal of an utterance thus differs from its representation in writing: The spaces between the written words are generally missing in speech. Does this mean that because we do not pronounce utterances word by word, our perception that utterances are made up of words is a kind of illusion—that we perceive words even though they are not actually there?

I argue that this is indeed the case, for what we hear is only partly determined by the physical signal that strikes our ears. For instance, we generally hear words in utterances of only our own language; we fail to hear words in equally clear utterances in an unfamiliar language. Moreover, many utterances, even when pronounced perfectly clearly, are ambiguous, in the sense that they can be perceived as either of two (or sometimes more) distinctly different sequences of words.

A recent incident illustrates this quite well. Somebody reported to me that he had met a person with the interesting name

Me[lbə]tory,

in which ə represents the sound of *a* in *about*. “Oh, yes,” said I, “this person has the same last name as a sixteenth-century Polish king, Stefan Batory, who fought against the Turks.” As I began a minilecture on Turkey’s role as a major military power for many centuries, I was interrupted with the information that the person in question was female and that her first name was *Melba* and her last name *Torrey*. Although this name also provided the basis of an erudite disquisition, the opportunity somehow had passed. Be that as it may, the point of the anecdote is that the utterance was ambiguous, and that its ambiguity was not located in the acoustical signal nor in the intention of the speaker. The hearer’s misapprehension thus was due to the assumption (or illusion) that a particular sequence of sounds was divided into words in a way that did not coincide with the division intended by the speaker.

KNOWLEDGE: CONSCIOUS VS. UNCONSCIOUS

Since knowing words is an essential component of every fluent speaker’s command of language, an obvious topic to investigate is the form in which this knowledge is internalized by speakers: What do they know about the words of their language? At first blush it may appear that the answer is trivially simple. Speakers know that certain sound sequences have particular meanings; for example, the sound sequence [dɔg] refers to the animal otherwise known as man’s best friend, whereas the sound sequence [tɔk] refers to the activity of speaking.

There is more to it, however. Speakers know not only the words of their language; they also know whether a given sound sequence could or could not be a word in their language. Consider the strings of letters in Table I. Most readers have never encountered any of these “words” before. Yet there will be widespread agreement that some of these *might* be English words whereas others could not possibly be English. Furthermore, most readers will agree as to which “words” belong where, i.e., *thrim*, *snork*, *dramp*, *platch*, and *shripe* are likely to be judged English words, while *gmet*, *lgal*, *vrag*, *pfin*, *bdit*, and *nsip* are not English. Since none of the “words” was pre-

TABLE I
SOME ENGLISH “NONWORDS”

thrim	lgal	dramp	pfin
platch	gmet	shripe	bdit
snork	vrag	chrde	nsip

viously encountered, the judgment cannot be the result of checking through a list of memorized words. The explanation must be that we all share some basic information about the structural properties of English words—for example, that English words never begin with the consonant clusters *gm* and *lg*, whereas *sn* and *pl* are allowed. In other words, we all share some abstract principles of word structure such as those in the illustration.

(The remarks concerning the “non-word” *gmet* are meant to refer to a pronunciation where both word-initial consonants are sounded. Phonetic consonant clusters such as [gn], [kn], [pm], [mn], etc. are indeed not admitted at the beginning of English words.)

It is unlikely that any readers will recall working out such principles in the course of learning English; in fact, few speakers will claim that they are even aware of knowing such principles. Yet their ability to judge “words” such as those cited above as English or not can only be explained by the assumption that speakers of English possess this type of knowledge. In other words, this suggests that we have knowledge about our native tongue of which we are not conscious. Like Molière’s M. Jourdain, we all speak prose, but we are totally unaware of doing so.

KNOWLEDGE: TAUGHT, LEARNED, AND INNATE

The existence of knowledge not directly accessible to our consciousness is not a particularly new discovery. One of the main purposes of Socrates’ questions in Plato’s writings was to demonstrate that even the most untutored among us possess knowledge of which we are totally unaware.

Many readers will accept this idea and yet be surprised that in passing on our language to our children we should be transmitting knowledge of which we ourselves are not consciously aware. Implicit in this surprise is the assumption that learning is always the result of overt teaching. But that assumption is false. Indeed, the acquisition of our mother tongue, I suggest, is a prime example of this kind of learning.

The fact that most of what we know about our native tongue is acquired without overt teaching raises a further question. All children are naturally interested in words and constantly inquire about them. But neither they nor their parents are the least bit curious about principles such as those illustrated in Table II that govern the distribution of initial consonant clusters. Yet somehow in the process of learning English we must have learned them. How can one explain this? How can one explain, in other words, that in the process of learning the words of English we incidentally learn principles of English word structure in which we have no conscious interest and to which nothing in our daily existence might plausibly draw our attention?

The only reasonable account of how speakers come to know these principles is to attribute them not to external factors but

to innate mechanisms involved in memorizing words—that is, to assume that our minds are so constructed that when we memorize words, we automatically also abstract their structural principles. We might suppose that human memory for words is at a premium so that every word must be stored in a maximally economical form, i.e., in a form where every redundancy is eliminated. Since the principles noted in Table II capture an essential aspect of the redundancy inherent in English words, access to these principles is required to store English words in their most economical form. Different principles will, of course, be developed for different languages, but there is no language that lacks them altogether, that does not place severe constraints on sequences of consonants and vowels in words. Thus, the postulated mechanism that causes speakers to seek the abstract structural principles in their words will always produce a useful result.

It almost goes without saying that the propensity to search for structural regularities in the words we commit to memory is not something that we acquire from experience. Try to imagine, for instance, what sort of experiences might lead a child of average intelligence to grasp the fact that words contain redundancies that might be utilized for more economical coding. Moreover, these experiences must be common to children of all cultures, to Greenland Eskimos as well as to those whose parents are, for example, college professors. The only plausible explanation for the special way in which humans memorize words is innate: We do it in our particular way because for members of our species there is no other way.

There is of course nothing implausible in the suggestion that an organism is genetically constructed to perform particular tasks in particular ways. In fact, that is surely a major reason why a particular organism executes certain tasks very well and others poorly or not at all. Think, for example, of a kitten that shares a young child's every waking moment. At the end of a year or two the child will have acquired substantial mastery over its mother tongue, but the pet will fail to show any progress of this kind; instead, it will show great skill at catching mice and climbing trees. The reason for this is that humans are genetically different from cats, and part of that difference consists of the intellectual capacities that enable humans to acquire command of a language, presumably through special built-in features that determine, among other things, the way we memorize words.

UNIVERSALS OF LANGUAGE?

If the basis of our command of a language is genetically predetermined, then we should expect to find similarities among the principles and rules of all the different languages that are or have been spoken by humans. And we do.

In every language there are rules that affect groups of sounds rather than individual sounds, and the same groups of sounds figure in the rules of widely differing languages. For example, consider [bdg]. One of the basic rules of Spanish phonetics states that these consonants are pronounced much as in English when they are the initial sound of a word and in certain other environments. However, they are pronounced very differently elsewhere, as shown in Table III. We recall the clusters of consonants in this same class [bdg] are excluded

TABLE II
SOME PRINCIPLES OF ENGLISH WORD STRUCTURE

1	mn	do not figure in any clusters except <i>sm</i> and <i>sm</i> ; <i>snail</i> and <i>small</i> are words, <i>gmet</i> is not a possible word.
2	mnlrwy	do not occupy the first position in a cluster; <i>platch</i> and <i>frith</i> are possible words, <i>lpatch</i> is not.
3	bdg	do not occupy the last position in a cluster; <i>bdt</i> is not a possible word.
4	ptkfe	may occupy either the first or the last position in a cluster, but not both; <i>thrim</i> , <i>sphere</i> , and <i>scare</i> are possible, but <i>pfm</i> is not.

TABLE III
THE SPECIAL VARIANTS OF b, d, AND g IN SPANISH

bajo	"low"	a[β]ajo	"below"
donde	"where"	a[ð]onde	"where to"
guardar	"to watch"	a[ɣ]uardar	"to wait for"

TABLE IV
THE GROUP [mnlrwy] IN PAPAGO

1	wawuk[ʔ]oo[ʔ]oo [ʔ]u[ʔ]uhig[ʔ]oo[ʔ]oo mawid[ʔ]oo[ʔ]oo	"raccoon bone" "bird bone" "mountain lion bone"
2	ba[ʔ]noo[ʔ]oo kaa[ʔ]woo[ʔ]oo ceeko[ʔ]loo[ʔ]oo	"coyote bone" "badger bone" "squirrel bone"

from last position in English words (Table II). Thus, this class figures in rules of two such distantly related languages as English and Spanish.

Similarly, the class of consonants [mnlrwy] receives special treatment in the Papago language spoken by Indians native to Arizona, as shown in Table IV; here those consonants figure in compound nouns, the second element of which is [ʔooʔoo], meaning "bone." In compounding, as the illustration shows, nouns are simply adjoined. However, adjoining consonants permute position, as in Table IV, when the first noun ends with a consonant from the set [mnlrwy] and the initial consonant of the second noun is a glottal stop [ʔ], a sound that in English we pronounce when we attempt to distinguish *an aim* from *a name*. Thus, when *wawuk* (raccoon) is adjoined to *ʔooʔoo*, the result is *wawukʔooʔoo*, but when *ban* (coyote) is adjoined to *ʔooʔoo*, the result is not *banʔooʔoo* but *baʔnooʔoo*.

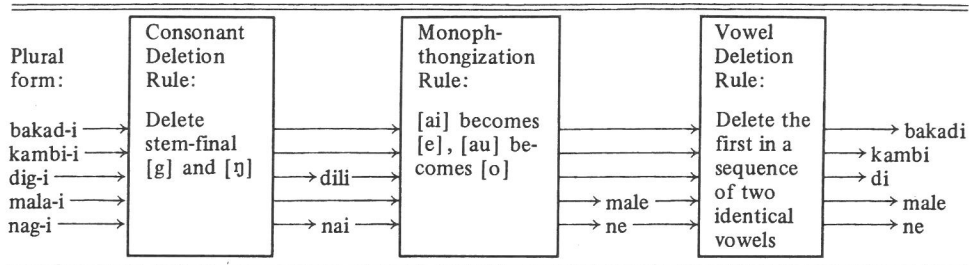
The same group [mnlrwy] that figures in the Papago rule of noun-compounding plays a role in English; the group is excluded from initial-consonant clusters in English words (see row 2 in Table II).

These examples—and experienced linguists should have little difficulty in extending the list indefinitely—show that identical groups of consonants function in totally unrelated languages. Indeed, the same groupings of sounds reemerge in the rules of language after language, whereas other groupings of sounds—e.g., [nlbk] or [ɐkrɔm]—are never encountered. This observation suggests that to the human speaker there is something natural about certain groupings of sounds—that they somehow belong together—whereas other groupings are unnatural and therefore never encountered. The judgment as to what sounds naturally belong together probably derives

TABLE V
THE PLURAL FORMS OF KASEM

	Singular	Plural		Singular	Plural	
1	bakadi	bakadi	“boy”	fala	fali	“white man”
2	kambia	kambi	“cooking pot”	pia	pi	“yam”
3	bua	bui	“river”	diga	di	“room”
4	mala	male	“chameleon”	kaba	kabe	“slave”
5	naga	ne	“leg”	la[ŋ]a	le	“song”

TABLE VI
SOME EXAMPLES OF RULES OPERATING ON KASEM PLURALS



from the design of our nervous system; and that, in turn, is determined by our genetic endowment.

FORMING WORDS FROM WORDS

Rules and principles of language are not at all something esoteric that only linguists and other pedants enjoy splitting hairs over. On the contrary, rules are the very stuff of which language is made, and speakers use them with the greatest ease, even abandon. Indeed, the rules and principles that determine the shape of the words in a language make up only a fraction of those regularly mastered by fluent speakers of the language.

To convey some impression of the exuberance with which languages use rules, let me briefly discuss part of the system of plural rules in Kasem, a language spoken by about 80 000 people in West Africa, primarily in Ghana. For the class of nouns shown in Table V, the singular forms end with the suffix *a* and the plural forms end with the suffix *i*. The suffixes appear in this form in row 1 (*bakada-bakadi* and *fala-fali*). The same suffixes are involved in the other examples, but their appearance there is masked by the effects of special rules.

For example, Kasem is subject to a rule that deletes the first in a sequence of identical vowels. Because of this Vowel Deletion Rule, the plural forms in row 2 are not *kambii* and *pii*, but *kambi* and *pi*.

A different rule—the Consonant Deletion Rule—accounts for the forms in row 3. This rule deletes stem-final [g] and [ŋ] in the plural. Consequently, in place of the expected *bugi* we get *bui*, and the plural of *diga* is not *digi* but *di*. The form *di* is somewhat more complicated than is first apparent. We know that the Consonant Deletion Rule would delete the *g* in *digi*, turning it into *dii*, but that is not the correct form; the correct form is *di*. There is, of course, no difficulty explaining how *di* arose: *dii* was subject to the Vowel Deletion Rule.

In the derivation of *di*, the two rules were applied in a specific order. If the rules had been applied in the reverse order, the result would have been *dii*. Since the basic form *digi* does not

contain a sequence of identical vowels it could not be subject to Vowel Deletion. The subsequent application of Consonant Deletion would then produce *dii*, but to this form Vowel Deletion can no longer apply since this rule has been ordered before (not after) Consonant Deletion.

A further complication arises in the case of *mala*, chameleon (row 4). The plural form should be *malai*; instead we find *male*. To a linguist this is not strange, because linguists know numerous languages where as a result of the Monophthongization Rule, the diphthong [ai] is replaced by the monophthong [e]. In fact, English spelling still shows traces of this development; the letter sequence *ai* is pronounced *e* as in *pain*, *maim*, and *gain*. This process is even more general in Kasem, with not only [ai] becoming [e] but also [au] becoming [o]. Now we are in a position to explain the forms in row 5 of Table V: They are the result of the interaction of the Consonant Deletion Rule with the Monophthongization Rule. Specifically, the basic plural forms *nagi* and *la[ŋ]i* are transformed by the Consonant Deletion Rule into *nai* and *lai*, respectively. They are then turned into *ne* and *le* by the Monophthongization Rule.

The fact that Kasem speakers use special rules to generate the plural forms of their nouns should not seem strange in light of what we have said. What may strike the layperson as implausible is the relative complexity of the procedure—outlined only incompletely in Table VI—that appears to be involved in the inflection of Kasem words. We might well wonder whether we really go to all this trouble just to say a few words.

Implicit in this objection is the assumption that humans find it difficult to perform this sort of computation—that it would be easier to memorize such facts as the plural of *naga* is *ne* and that of *diga* is *di* than to postulate a single plural suffix *i* for all nouns in this class and to compute the different outputs according to the rules. The linguistic evidence suggests that the converse is much closer to the truth, for the Kasem example is the norm rather than the exception. Indeed, recourse to

TABLE VII
RULES OF A LANGUAGE INVENTED BY CHILDREN

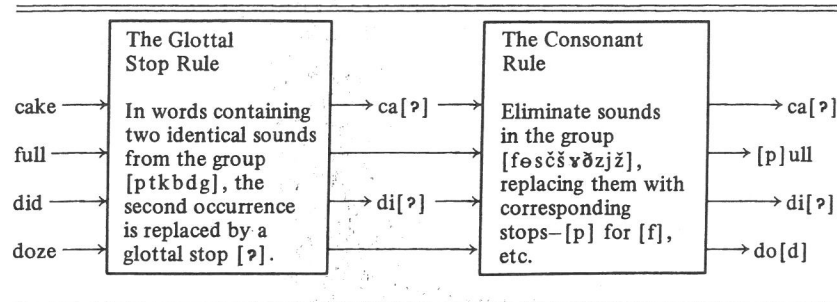


TABLE VIII
SOME WORDS IN A LANGUAGE INVENTED BY CHILDREN

1	cake	ca[ʔ]	daddy	da[ʔ]y	paper	pa[ʔ]er
2	full	[p]ull	pays	pay[d]	walks	walk[t]
	pull	[p]ull	paid	paid	walked	walk[t]
3	suit	[t]uit	doze	do[d]	fife	[p]i[p]
	toot	too[ʔ]	did	di[ʔ]	pipe	pi[ʔ]

computation is so strongly favored over rote memory that speakers apparently do not have the option of forsaking rules for memorization.

OWHAY ANCAY OUYAY EADRAY ISTHAY?

This natural bent for rules is expressed in a great many special uses of language. Children frequently use secret languages such as Ab-language or pig Latin, both of which are nothing but normal English to which one or two extra rules have been added. The rules for pig Latin, for instance, consist of a permutation that moves the initial consonant cluster from the beginning to the end of the word, to which the diphthong *ay* is then adjoined. Thus, *pig* becomes *igpay* and *Latin* becomes *atinlay*. These simple rules produce words so greatly at variance with standard English that children effectively possess a secret language quite impenetrable to their teachers and parents, which is, of course, the main purpose. Though to my knowledge the history of pig Latin has not been documented in detail, we know that it goes back many generations; today's speakers are not its inventors but have learned it from older children.

There are, however, numerous instances of secret languages invented by children. One such "language" was discovered about 20 years ago in Cambridge by Professor Joseph Applegate[1], then a member of the Department of Modern Languages at M.I.T. A couple living in his building consulted Professor Applegate about their two younger boys who, they feared, were suffering from some neurological disorder. Although they appeared to understand English, the boys were speaking a jargon that the parents found quite incomprehensible. The third child in the family, who was a few years older than the two problem children, had apparently no trouble understanding his brothers and often acted as their translator. After listening to the children for a few evenings, Professor Applegate discovered that the children were using a secret language of their own devising: By adding two rules to standard English, they were rendering their language quite impenetrable to their parents—although not to their brother.

Specifically, Professor Applegate found that the children's speech was modified by two rules absent from their parents' English (Table VII). In words containing two identical stops—i.e., two occurrences of a sound from the set [ptk b d g]—the children's speech was subject to a Glottal Stop Rule that replaced the second stop by a glottal stop [ʔ]. The children therefore pronounced words such as *cake*, *daddy*, and *paper* as shown in group 1 of Table VIII.

Second, the children's speech lacked affricates and fricatives—i.e., sounds belonging to the set [fəʃčšʋðzjž] were not used. In the children's language, a Consonant Rule replaced these with the corresponding stops—[f] by [p], [əʃčš] by [t], [v] by [b], and [ðzjž] by [d]. As a result, the children pronounced alike words that are differentiated in adult speech, as shown in groups 2 and 3 of the table.

That was not all, however. The children differentiated the stop sound that arose by the Consonant Rule from all other stop sounds: Only the latter were replaced by glottal stops as a result of the Glottal Stop Rule. (Additional examples are shown in group 3.) These rules, like those in the Kasem plural formation, were applied in a definite order, first the Glottal Stop Rule and then the Consonant Rule. Thus, *did* became *di[ʔ]* by the Glottal Stop Rule, and the Consonant Rule was not applicable. On the other hand, *doze*, to which the Glottal Stop Rule was not applicable, became *do[d]* by the Consonant Rule. Since the rules are ordered, it is impossible at this point to apply the Glottal Stop Rule again.

While this system may seem surprisingly sophisticated, both it and the rules of Kasem are instances of the human tendency to use rules—with sometimes unexpected results. In the case of the Cambridge children, the tendency was used to obstruct rather than facilitate communication.

LANGUAGE AS GENETIC ENDOWMENT

To summarize, the core of knowledge that fluent speakers have of their language has the form of rules, and these rules go well beyond what is directly observable in the movements executed by our vocal organs in speaking and the resulting

acoustic signals. Each language has its own special set of rules, and these rules constitute the essence of what we learn when we acquire mastery of a given language. In learning these rules, young children require no special instruction, and much of what they—or, for that matter, any language students—learn never enters their consciousness. Underlying these rules is a set of highly abstract hypotheses about language, including such propositions as these: Speech is made up of words; words, in turn, are made up of sequences of sounds subject to definite rules; the rules affect specific groups of sounds; the same groups of sounds figure in other rules in English as well as in other languages; and the rules of any given language interact in the fashion shown by the Kasem plurals and the children's secret language.

The highly sophisticated character of these propositions excludes the possibility that they are acquired through exper-

ience. Yet the attainment of fluent command of a language by a native speaker crucially implies access to these and similar propositions. The conclusion, therefore, is that these propositions are a special aspect of the human genetic endowment, that they are part of what makes our species distinct from all others.

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CAD/CAM—Bridging the Gap from Design to Production

JOHN K. KROUSE

Abstract—An engineer can use a computer to design a component, analyze its stresses, and check its mechanical action (CAD = computer-aided design). Production people can use the same computer to transform the design into hardware through numerical-control machining or other automated processes (CAM = computer-aided manufacturing). This paper describes the major CAD/CAM areas: geometric modeling, engineering analysis, kinematics, automated drafting/numerical control, process planning, robotics, factory management; shows how they are being integrated into unified systems; outlines the cooperative efforts of government, industry, and universities in CAD/CAM development; and lists sources of information.

TODAY a design engineer can define a part shape, analyze stresses and deflections, check its mechanical action, and automatically produce engineering drawings—all from the same graphics terminal of a computer-aided design (CAD) system. Furthermore, production people can draw upon the geometric description provided by CAD as a starting point to create numerical control (NC) tapes, determine process plans, instruct robots, and manage plant operations with computer-aided manufacturing (CAM).

These two technologies are now being combined into unified CAD/CAM systems, where a design is developed and the manufacturing process controlled from start to finish with a single system (Fig. 1). Such capabilities are presently available on the most sophisticated CAD/CAM systems in a few large

manufacturing operations. But more and more plants are gaining this capability. And experts predict that unified systems will lead to what forward-looking managers have long envisioned: the automated factory.

This evolution of CAD/CAM technology will result ultimately in the integration of many diverse technical areas that have developed separately for the past 30 years. Initially, CAD systems primarily were automated drafting stations in which computer-controlled plotters produced engineering drawings. The systems were later linked to graphic display terminals where a geometric model describing the part shape could be created, and the resulting data base in the computer was used to produce drawings. Graphic terminals allowed the user to communicate with the computer in pictures instead of raw columns of numbers and thus allowed access to the computer by users untrained in programming. Now, advanced systems based on interactive graphic terminals have analytical capabilities which permit the part to be evaluated with techniques such as the finite-element method. And kinematic programs allow the motion of mechanisms to be studied.

Concurrently with the development of CAD technology, CAM advancements were also being made, mostly in numerical control. Until recently, experienced programmers were required to produce and verify NC instructions. But now, instructions can be produced automatically for complex shapes, and tool paths can be verified quickly with computer simulation. In addition, these systems may also have limited process planning features for determining a sequence of fabrication steps and factory management capabilities for directing the

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