

[Unit 6: Applications of AI]
Artificial Intelligence (MDS 556)
Master in Data Science

Expert Systems:

An Expert system is a set of program that manipulates encoded knowledge to solve problem in a specialized domain that normally requires human expertise.

A computer system that simulates the **decision- making process** of a human expert in a specific domain.

An expert system's knowledge is obtained from expert sources and coded in a form suitable for the system to use in its inference or reasoning processes. The expert knowledge must be obtained from specialists or other sources of expertise, such as texts, journals, articles and data bases.

An expert system is an “intelligent” program that solves problems in a narrow problem area by using high-quality, specific knowledge rather than an algorithm.

Block Diagram

There is currently no such thing as “standard” expert system. Because a variety of techniques are used to create expert systems, they differ as widely as the programmers who develop them and the problems they are designed to solve. However, the principal components of most expert systems are **knowledge base, an inference engine, and a user interface**, as illustrated in the figure.

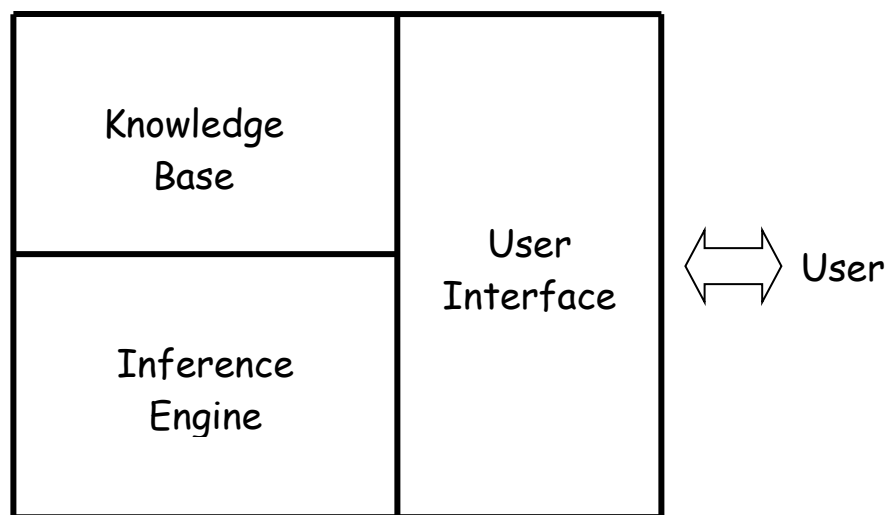


Fig: Block Diagram of expert system

1. Knowledge Base

The component of an expert system that contains the system's knowledge is called its knowledge base. This element of the system is so critical to the way most expert systems are constructed that they are also popularly known as *knowledge-based systems*.

A knowledge base contains both declarative knowledge (facts about objects, events and situations) and procedural knowledge (information about courses of action). Depending on the form of knowledge representation chosen, the two types of knowledge may be separate or integrated. Although many knowledge representation techniques have been used in expert systems, the most prevalent form of knowledge representation currently used in expert systems is the *rule-based production* system approach.

To improve the performance of an expert system, we should supply the system with some knowledge about the knowledge it possesses, or in other words, meta-knowledge.

2. Inference Engine

Simply having access to a great deal of knowledge does not make you an expert; you also must know **how** and **when** to apply the appropriate knowledge. Similarly, just having a knowledge base does not make an expert system intelligent. The system must have another component that directs the implementation of the knowledge. That element of the system is known variously as the *control structure*, the *rule interpreter*, or the *inference engine*.

The inference engine decides which heuristic search techniques are used to determine how the rules in the knowledge base are to be applied to the problem. In effect, an inference engine “runs” an expert system, determining which rules are to be invoked, accessing the appropriate rules in the knowledge base, executing the rules, and determining when an acceptable solution has been found.

3. User Interface

The component of an expert system that communicates with the user is known as the *user interface*. The communication performed by a user interface is bidirectional. At the simplest level, we must be able to describe our problem to the expert system, and the system must be able to respond with its recommendations. We may want to ask the system to explain its “reasoning”, or the system may request additional information about the problem from us.

Beside these three components, there is a Working Memory - a data structure which stores information about a specific run. It holds current facts and knowledge.

Stages of Expert System Development:

Although great strides have been made in expediting the process of developing an expert system, it often remains an extremely time consuming task. It may be possible for one or two people to develop a small expert system in a few months; however the development of a sophisticated system may require a team of several people working together for more than a year.

An expert system typically is developed and refined over a period of several years. We can divide the process of expert system development into five distinct stages. In practice, it may not be possible to break down the expert system development cycle precisely. However, an examination of these five stages may serve to provide us with some insight into the ways in which expert systems are developed.

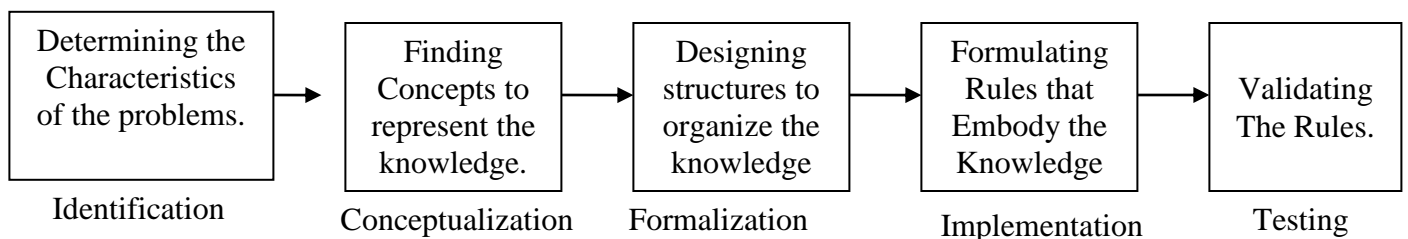


Fig: Different phases of expert system development

Identification:

Beside we can begin to develop an expert system, it is important that we describe, with as much precision as possible, the problem that the system is intended to solve. It is not enough simply to feel that the system would be helpful in certain situation; we must determine the exact nature of the problem and state the precise goals that indicate exactly how we expect the expert system to contribute to the solution.

Conceptualization:

Once we have formally identified the problem that an expert system is to solve, the next stage involves analyzing the problem further to ensure that its specifics, as well as its generalities, are understood. In the conceptualization stage the **knowledge engineer** frequently creates a diagram of the problem to depict graphically the relationships between the objects and processes in the problem domain. It is often helpful at this stage to divide the problem into a series of sub-problems and to diagram both the relationships among the pieces of each sub-problem and the relationships among the various sub-problems.

Formalization:

In the preceding stages, no effort has been made to relate the domain problem to the artificial intelligence technology that may solve it. During the identification and the conceptualization stages, the focus is entirely on understanding the problem. Now, during the formalization stage, the problem is connected to its proposed solution, an expert system, by analyzing the relationships depicted in the conceptualization stage.

During formalization, it is important that the knowledge engineer be familiar with the following:

- The various techniques of knowledge representation and heuristic search used in expert systems.
- The expert system “tools” that can greatly expedite the development process. And
- Other expert systems that may solve similar problems and thus may be adequate to the problem at hand.

Implementation:

During the implementation stage, the formalized concepts are **programmed** onto the computer that has been chosen for system development, using the predetermined techniques and tools to implement a “first pass” prototype of the expert system.

Theoretically, if the methods of the previous stage have been followed with diligence and care, the implementation of the prototype should be as much an art as it is a science, because following all rules does not guarantee that the system will work the first time it is implemented. Many scientists actually consider the first prototype to be a “throw-away” system, useful for evaluating progress but hardly a usable expert system.

Testing:

Testing provides opportunities to identify the weakness in the structure and implementation of the system and to make the appropriate corrections. Depending on the types of problems encountered, the testing procedure may indicate that the system was

Features of an expert system:

What are the features of a good expert system? Although each expert system has its own particular characteristics, there are several features common to many systems. The following list from Rule-Based Expert Systems suggests seven criteria that are important prerequisites for the acceptance of an expert system .

1. “The program should be **useful**.” An expert system should be developed to meet a specific need, one for which it is recognized that assistance is needed.

2. “The program should be **usable**.” An expert system should be designed so that even a novice computer user finds it easy to use.
3. “The program should be **educational when appropriate**.” An expert system may be used by non-experts, who should be able to increase their own expertise by using the system.
4. “The program should be able to **explain its advice**.” An expert system should be able to explain the “reasoning” process that led it to its conclusions, to allow us to decide whether to accept the system’s recommendations.
5. “The program should be able to **respond to simple questions**.” Because people with different levels of knowledge may use the system, an expert system should be able to answer questions about points that may not be clear to all users.
6. “The program should be able to **learn new knowledge**.” Not only should an expert system be able to respond to our questions, it also should be able to ask questions to gain additional information.
7. “The program’s knowledge should be **easily modified**.” It is important that we should be able to revise the knowledge base of an expert system easily to correct errors or add new information.

Natural Language Processing

Perception and communication are essential components of intelligent behavior. They provide the ability to effectively interact with our environment. Humans perceive and communicate through their five basic senses of sight, hearing, touch, smell and taste, and their ability to generate meaningful utterances. Developing programs that understand a natural language is a difficult problem. Natural languages are large. They contain infinity of different sentences. No matter how many sentences a person has heard or seen, new ones can always be produced. Also, there is much ambiguity in a natural language. Many words have several meanings and sentences can have different meanings in different contexts. This makes the creation of programs that understand a natural language, one of the most challenging tasks in AI.

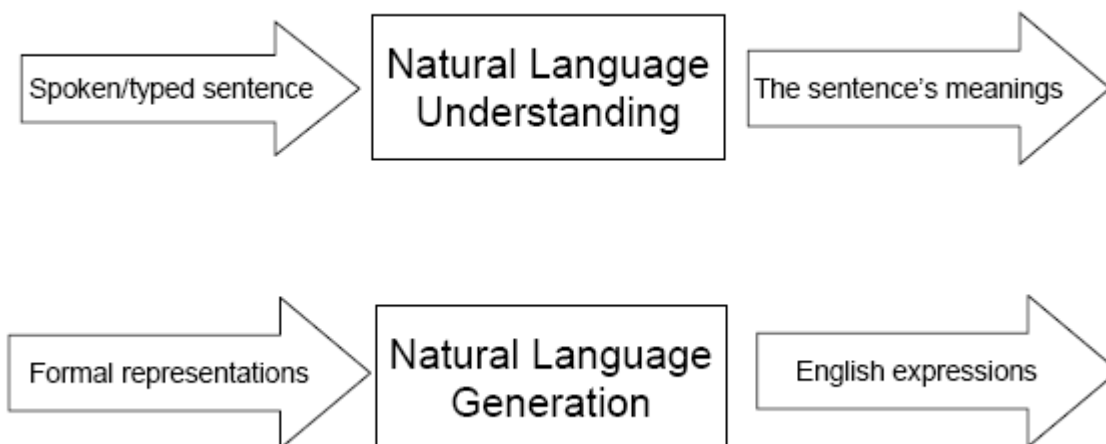
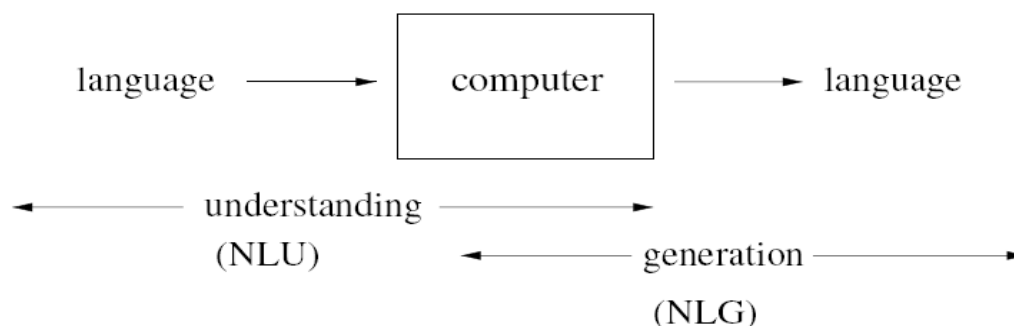
Developing programs to understand natural language is important in AI because a natural form of communication with systems is essential for user acceptance. AI programs must be able to communicate with their human counterparts in a natural way, and natural language is one of the most important mediums for that purpose. So, Natural Language Processing (NLP) is the field that deals with the computer processing of natural languages, mainly evolved by people working in the field of Artificial Intelligence.

Natural Language Processing (NLP), is the attempt to extract the fuller meaning representation from the free text. Natural language processing is a technology which

involves converting spoken or written human language into a form which can be processed by computers, and vice versa. Some of the better-known applications of NLP include:

- **Voice recognition software** which translates speech into input for word processors or other applications;
- **Text-to-speech synthesizers** which read text aloud for users such as the hearing-impaired;
- **Grammar and style checkers** which analyze text in an attempt to highlight errors of grammar or usage;
- **Machine translation systems** which automatically render a document such as a web page in another language.

computers using natural language as input and/or output



Natural Language Generation:

"Natural Language Generation (NLG), also referred to as text generation, is a subfield of natural language processing (NLP; which includes computational linguistics)

Natural Language Generation (NLG) is the natural language processing task of generating natural language from a machine representation system such as a knowledge base or a logical form.

In a sense, one can say that an NLG system is like a translator that converts a computer based representation into a natural language representation. However, the methods to produce the final language are very different from those of a compiler due to the inherent expressivity of natural languages.

NLG may be viewed as the opposite of natural language understanding. The difference can be put this way: whereas in natural language understanding the system needs to disambiguate the input sentence to produce the machine representation language, in NLG the system needs to make decisions about how to put a concept into words.

The different types of generation techniques can be classified into four main categories:

- Canned text systems constitute the simplest approach for single-sentence and multi-sentence text generation. They are trivial to create, but very inflexible.
- Template systems, the next level of sophistication, rely on the application of pre-defined templates or schemas and are able to support flexible alterations. The template approach is used mainly for multi-sentence generation, particularly in applications whose texts are fairly regular in structure.
- Phrase-based systems employ what can be seen as generalized templates. In such systems, a phrasal pattern is first selected to match the top level of the input, and then each part of the pattern is recursively expanded into a more specific phrasal pattern that matches some subportion of the input. At the sentence level, the phrases resemble phrase structure grammar rules and at the discourse level they play the role of text plans.
- Feature-based systems, which are as yet restricted to single-sentence generation, represent each possible minimal alternative of expression by a single feature. Accordingly, each sentence is specified by a unique set of features. In this framework, generation consists in the incremental collection of features appropriate for each portion of the input. Feature collection itself can either be based on unification or on the traversal of a feature selection network. The expressive power of the approach is very high since any distinction in language can be added to the system as a feature. Sophisticated feature-based generators, however, require very complex input and make it difficult to maintain feature interrelationships and control feature selection.

Many natural language generation systems follow a hybrid approach by combining components that utilize different techniques.

Natural Language Understanding:

Developing programs that understand a natural language is a difficult problem. Natural languages are large. They contain infinity of different sentences. No matter how many sentences a person has heard or seen, new ones can always be produced. Also, there is much ambiguity in a natural language. Many words have several meanings such as can, bear, fly, bank etc, and sentences have different meanings in different contexts.

Example :- A *can* of juice. I *can* do it.

This makes the creation of programs that understand a natural language, one of the most challenging tasks in AI. Understanding the language is not only the transmission of words. It also requires inference about the speakers' goal, knowledge as well as the context of the interaction. We say a program understands natural language if it behaves by taking the correct or acceptable action in response to the input. A word functions in a sentence as a part of speech. Parts of the speech for the English language are nouns, pronouns, verbs, adjectives, adverbs, prepositions, conjunctions and interjections. Three major issues involved in understanding language.

- A large amount of human knowledge is assumed.
- Language is pattern based, phonemes are components of the words and words make phrases and sentences. Phonemes, words and sentences order are not random.
- Language acts are the product of agents (human or machine).

Levels of knowledge used in Language Understanding

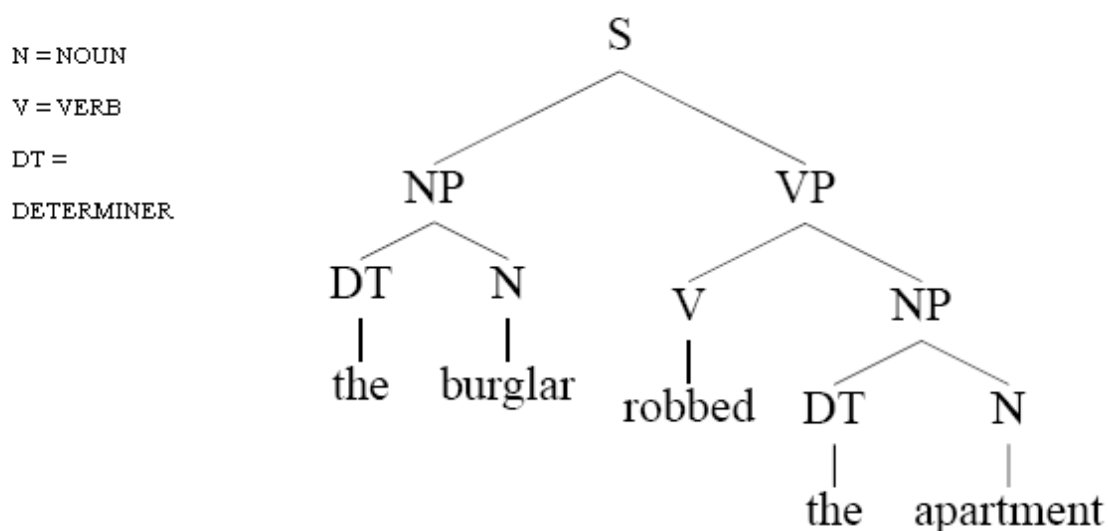
A language understanding knowledge must have considerable knowledge about the structures of the language including what the words are and how they combine into phrases and sentences. It must also know the meanings of the words and how they contribute to the meanings of the sentence and to the context within which they are being used. The component forms of knowledge needed for an understanding of natural languages are sometimes classified according to the following levels.

- **Phonological**
 - Relates sound to the words we recognize. A phoneme is the smallest unit of the sound. Phones are aggregated to the words.
- **Morphological**
 - This is lexical knowledge which relates to the word construction from basic units called morphemes. A morpheme is the smallest unit of meaning. Eg:- *friend* + *ly* = friendly
- **Syntactic**

- This knowledge relates to how words are put together or structured together to form grammatically correct sentences in the language.
- **Semantic**
 - This knowledge is concerned with the meanings of words and phrases and how they combine to form sentence meaning.
- **Pragmatic**
 - This is high – level knowledge which relates to the use of sentences in different contexts and how the context affects the meaning of the sentence.
- **World**
 - Includes the knowledge of the physical world, the world of human social interaction, and the roles of goals and intentions in communication.

Basic Parsing Techniques

Before the meaning of a sentence can be determined, the meanings of its constituent parts must be established. This requires knowledge of the structure of the sentence, the meaning of the individual words and how the words modify each other. The process of determining the syntactical structure of a sentence is known as parsing. Parsing is the process of analyzing a sentence by taking it apart word – by – word and determining its structure from its constituent parts and sub parts. The structure of a sentence can be represented with a syntactic tree. When given an input string, the lexical parts or terms (root words), must first be identified by type and then the role they play in a sentence must be determined. These parts can be combined successively into larger units until a complete tree has been computed.



Noun Phrases (NP): “the burglar”, “the apartment”

Verb Phrases (VP): “robbed the apartment”

Sentences (S): “the burglar robbed the apartment”

To determine the meaning of a word, a parser must have access to a lexicon. When the parser selects the word from the input stream, it locates the word in the lexicon and obtains the word’s possible functions and features, including the semantic information.

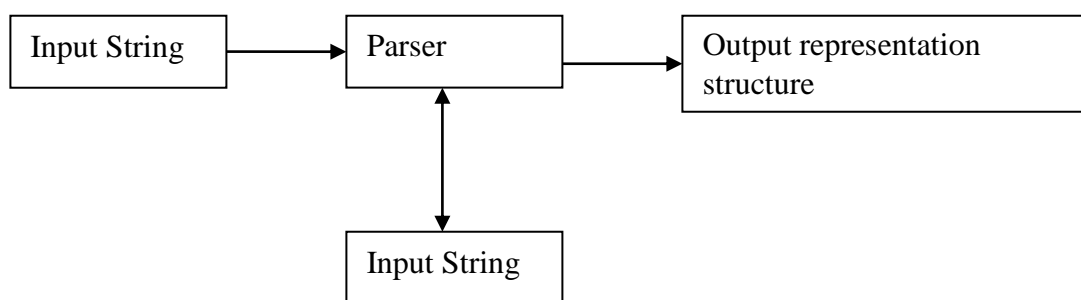


Figure :- Parsing an input to create an output structure

Lexeme (Lexicon) & word forms:

The distinction between these two senses of "word" is arguably the most important one in morphology. The first sense of "word", the one in which *dog* and *dogs* are "the same

word", is called a lexeme. The second sense is called *word form*. We thus say that *dog* and *dogs* are different forms of the same lexeme. *Dog* and *dog catcher*, on the other hand, are different lexemes, as they refer to two different kinds of entities. The form of a word that is chosen conventionally to represent the canonical form of a word is called a lemma, or citation form.

A lexicon defines the words of a language that a system knows about. This includes common words and words that are specific to the domain of the application. Entries include meanings for each word and its syntactic and morphological behavior.

Morphology:

Morphology is the identification, analysis and description of the structure of words (words as units in the lexicon are the subject matter of lexicology). While words are generally accepted as being (with clitics) the smallest units of syntax, it is clear that in most (if not all) languages, words can be related to other words by rules. For example, English speakers recognize that the words *dog*, *dogs*, and *dog catcher* are closely related. English speakers recognize these relations from their tacit knowledge of the rules of word formation in English. They infer intuitively that *dog* is to *dogs* as *cat* is to *cats*; similarly, *dog* is to *dog catcher* as *dish* is to *dishwasher* (in one sense). The rules understood by the speaker reflect specific patterns (or regularities) in the way words are formed from smaller units and how those smaller units interact in speech. In this way, morphology is the branch of linguistics that studies patterns of word formation within and across languages, and attempts to formulate rules that model the knowledge of the speakers of those languages.

Morphological analysis is the process of recognizing the suffixes and prefixes that have been attached to a word.

We do this by having a table of affixes and trying to match the input as:
prefixes + root + suffixes.

- For example: adjective + ly -> adverb. E.g.: [Friend + ly]=friendly
- We may not get a unique result.
- “-s, -es” can be either a plural noun or a 3ps verb
- “-d, -ed” can be either a past tense or a perfect participle

Morphological Information:

- Transform part of speech
 - *green, greenness* (adjective, noun)
 - *walk, walker* (verb, noun)
- Change features of nouns
 - *boat, boats* (singular, plural)
- Bill slept , Bill’s bed

- (subjective case, possessive case)
- Change features of verbs
 - Aspect
 - *I walk. I am walking.* (present, progressive)
 - Tense
 - *I walked. I will walk. I had been walking.* (past, future, past progressive)
 - Number and person
 - *I walk. They walk.* (first person singular, third person plural)

Syntactic Analysis:

Syntactic analysis takes an input sentence and produces a representation of its grammatical structure. A grammar describes the valid parts of speech of a language and how to combine them into phrases. The grammar of English is nearly context free.

A computer grammar specifies which sentences are in a language and their parse trees. A parse tree is a hierarchical structure that shows how the grammar applies to the input. Each level of the tree corresponds to the application of one grammar rule.

It is the starting point for working out the meaning of the whole sentence. Consider the following two sentences.

1. “The dog ate the bone.”
2. “The bone was eaten by the dog.”

Understanding the structure (via the syntax rules) of the sentences help us work out that it's the bone that gets eaten and not the dog. Syntactic analysis determines possible grouping of words in a sentence. In other cases there may be many possible groupings of words. Consider the sentence “John saw Mary with a telescope”. Two different readings based on the groupings.

1. John saw (Mary with a telescope).
2. John (saw Mary with a telescope).

A sentence is syntactically ambiguous if there are two or more possible groupings. Syntactic analysis helps determining the meaning of a sentence by working out possible word structure. Rules of syntax are specified by writing a *grammar* for the language. A parser will check if a sentence is correct according to the grammar. It returns a representation (parse tree) of the sentence's structure. A grammar specifies allowable sentence structures in terms of basic categories such as noun and verbs. A given grammar, however, is unlikely to cover all possible grammatical sentences. Parsing sentences is to help determining their meanings, not just to check that they are correct. Suppose we want a grammar that recognizes sentences like the following.

John ate the biscuit.
 The lion ate the zebra.
 The lion kissed John

But reject incorrect sentences such as

Ate John biscuit the.
 Zebra the lion the ate.
 Biscuit lion kissed.

A simple grammar that deals with this is given below

sentence --> noun_phrase, verb_phrase.

noun_phrase --> proper_noun.

noun_phrase --> determiner, noun.

verb_phrase --> verb, noun_phrase.

proper_noun --> [mary].

proper_noun --> [john].

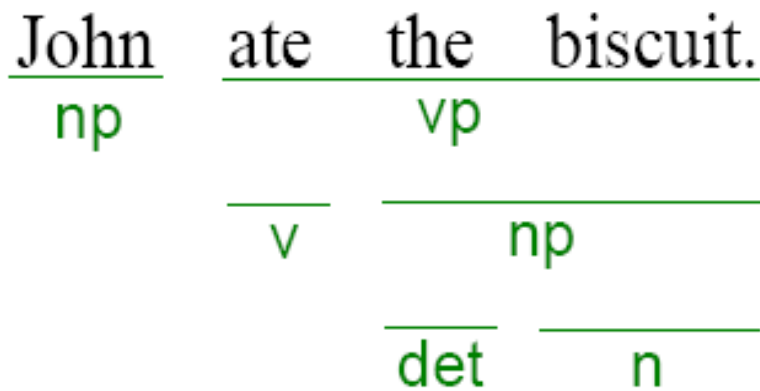
noun --> [zebra].

noun --> [biscuit].

verb --> [ate].

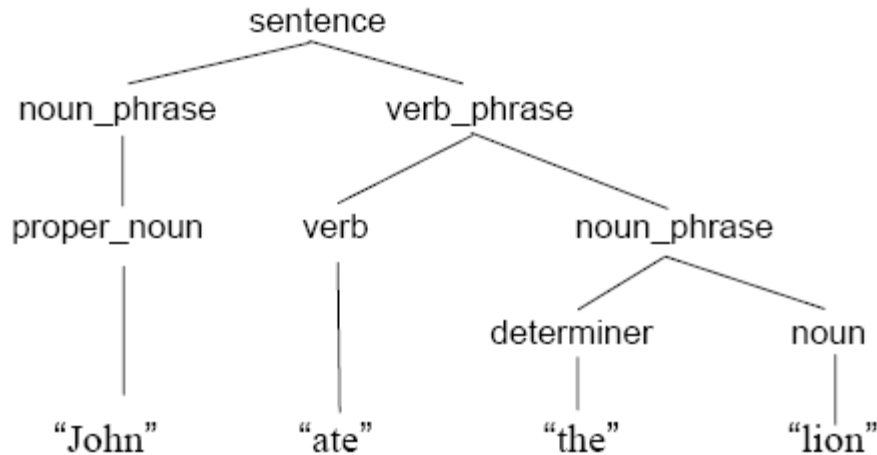
verb --> [kissed].

determiner --> [the].



Incorrect sentences like “biscuit lion kissed” will be excluded by the grammar.

- A **parse trees** illustrates the syntactic structure of the sentence.



Semantic Analysis:

Semantic analysis is a process of converting the syntactic representations into a meaning representation.

This involves the following tasks:

- Word sense determination
- Sentence level analysis
- Knowledge representation

- Word sense

Words have different meanings in different contexts.

Mary had a bat in her office.

- bat = 'a baseball thing'
- bat = 'a flying mammal'

- Sentence level analysis

Once the words are understood, the sentence must be assigned some meaning

I saw an astronomer with a telescope.

- Knowledge Representation

Understanding language requires lots of knowledge.

- Using predicate logic, for example, one can represent sentences like

“John likes Mary” $\text{likes}(\text{john}, \text{mary})$

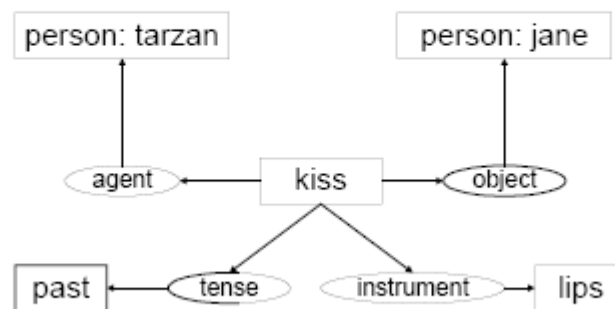
“The man likes Mary” $\text{man}(\text{m1}) \wedge \text{likes}(\text{m1}, \text{mary})$

“A man likes Mary” $\exists X(\text{man}(X) \wedge \text{likes}(X, \text{mary}))$

“A tall bearded man likes Mary”

$\exists X(\text{man}(X) \wedge \text{tall}(X) \wedge \text{bearded}(X) \wedge \text{likes}(X, \text{mary}))$

- Using semantic net, one can represent sentence “Tarzan kissed Jane” as



Parameters in Natural Language Processing:

- Auditory Inputs
- Segmentation
- Syntax Structure
- Semantic Structure
- Pragmatic Analysis

- Auditory Inputs:

Three of our five senses – sight, hearing and touch – are used as *major inputs*. These are usually referred to as the visual, auditory and tactile inputs respectively. They are sometimes called input channels; however, as previously mentioned, the term "channel" is used in various ways, so I will avoid it.

In the fashion of video devices, audio devices are used to either capture or create sound. In some cases, an audio output device can be used as an input device, in order to capture produced sound.

- Microphone
- MIDI keyboard or other digital musical instrument

- Segmentation:

Text segmentation is the process of dividing written text into meaningful units, such as words, sentences, or topics. The term applies both to mental processes used by humans when reading text, and to artificial processes implemented in computers, which are the subject of natural language processing. The problem is non-trivial, because while some written languages have explicit word boundary markers, such as the word spaces of written English and the distinctive initial, medial and final letter shapes of Arabic, such signals are sometimes ambiguous and not present in all written languages.

Word segmentation is the problem of dividing a string of written language into its component words. In English and many other languages using some form of the Latin alphabet, the space is a good approximation of a word delimiter. (Some examples where the space character alone may not be sufficient include contractions like *can't* for *can not*.)

However the equivalent to this character is not found in all written scripts, and without it word segmentation is a difficult problem. Languages which do not have a trivial word segmentation process include Chinese, Japanese, where sentences but not words are delimited, and Thai, where phrases and sentences but not words are delimited.

In some writing systems however, such as the Ge'ez script used for Amharic and Tigrinya among other languages, words are explicitly delimited (at least historically) with a non-whitespace character.

Word splitting is the process of parsing concatenated text (i.e. text that contains no spaces or other word separators) to infer where word breaks exist.

Sentence segmentation is the problem of dividing a string of written language into its component sentences. In English and some other languages, using punctuation, particularly the full stop character is a reasonable approximation. However, even in English this problem is not trivial due to the use of the full stop character for abbreviations, which may or may not also terminate a sentence. For example *Mr.* is not its own sentence in "*Mr. Smith went to the shops in Jones Street.*" When processing plain text, tables of abbreviations that contain periods can help prevent incorrect assignment of sentence boundaries. As with word segmentation, not all written languages contain punctuation characters which are useful for approximating sentence boundaries.

Other segmentation problems: Processes may be required to segment text into segments besides words, including morphemes (a task usually called morphological analysis), paragraphs, topics or discourse turns.

A document may contain multiple topics, and the task of computerized text segmentation may be to discover these topics automatically and segment the text accordingly. The topic boundaries may be apparent from section titles and paragraphs. In other cases one needs to use techniques similar to those used in document classification. Many different approaches have been tried.

- Syntax Structure:

Same concept as in the syntactic analysis above

- Semantic Structure:

Same concept as in the semantic analysis above

- Pragmatic Analysis:

This is high level knowledge which relates to the use of sentences in different contexts and how the context affects the meaning of the sentences. It is the study of the ways in which language is used and its effect on the listener. Pragmatic comprises aspects of meaning that depend upon the context or upon facts about real world.

Pragmatics – Handling Pronouns

Handling pronouns such as “he”, “she” and “it” is not always straight forward. Let us see the following paragraph.

“John buys a new telescope. He sees Mary in the distance. He gets out his telescope. He looks at her through it”.

Here, “*her*” refers to *Mary* who was not mentioned at all in the previous sentences. John’s telescope was referred to as “*a new telescope*”, “*his telescope*” and “*it*”.

Let us see one more example

“When is the next flight to Sydney?”
“Does it have any seat left?”

Here, “*it*”, refers to a particular flight to Sydney, not Sydney itself.

Pragmatics – Ambiguity in Language

A sentence may have more than one structure such as

“I saw an astronomer with a telescope.”

This English sentence has a prepositional phrase “*with a telescope*” which may be attached with either with verb to make phrase “*saw something with telescope*” or to object noun phrase to make phrase “*a astronomer with a telescope*”. If we do first, then it can be interpreted as “*I saw an astronomer who is having a telescope*”, and if we do second, it can be interpreted as “*Using a telescope I saw an astronomer*”.

Now, to remove such ambiguity, one possible idea is that we have to consider the context. If the knowledge base (KB) can prove that whether the telescope is with astronomer or not, then the problem is solved.

Next approach is that; let us consider the real scenario where the human beings communicate. If A says the same sentence “*I saw an astronomer with a telescope.*” To B, then in practical, it is more probable that, B (listener) realizes that “*A has seen astronomer who is having a telescope*”. It is because, normally, the word “*telescope*” belongs to “*astronomer*”, so it is obvious that B realizes so.

If A has says that “*I saw a lady with a telescope.*” In this case, B realizes that “*A has seen the lady using a telescope*”, because the word “*telescope*” has not any practical relationship with “*lady*” like “*astronomer*”.

So, we may be able to remove such ambiguity, by defining a data structure, which can efficiently handle such scenario. This idea may not 100% correct but seemed more probable.

Robotics

Robots are physical agents that perform tasks by manipulating the physical world. To do so, they are equipped with **effectors** such as legs, wheels, joints, and grippers. Effectors have a single purpose: to assert physical forces on the environment.¹ Robots are also equipped with **sensors**, which allow them to perceive their environment. Present day robotics employs a diverse set of sensors, including cameras and lasers to measure the environment, and gyroscopes and accelerometers to measure the robot’s own motion.

Most of today’s robots fall into one of three primary categories.

Manipulators, or robot arms, are physically anchored to their workplace, for example in a factory assembly line or on the International Space Station. Manipulator motion usually involves a chain of controllable joints, enabling such robots to place their effectors in any position within the workplace. Manipulators are by far the most common type of industrial robots, with approximately one million units installed worldwide. Some mobile manipulators are used in hospitals to assist surgeons. Few car manufacturers could survive without robotic manipulators, and some manipulators have even been used to generate original artwork.

The second category is the **mobile robot**. Mobile robots move about their environment using wheels, legs, or similar mechanisms. They have been put to use delivering food in hospitals, moving containers at loading docks, and similar tasks.

The third type of robot combines mobility with manipulation, and is often called a **mobile manipulator**. **Humanoid robots** mimic the human torso.

The field of robotics also includes prosthetic devices (artificial limbs, ears, and eyes for humans), intelligent environments (such as an entire house that is equipped with sensors and effectors), and multibody systems, wherein robotic action is achieved through swarms of small cooperating robots.

Robotics brings together many of the concepts including probabilistic state estimation, perception, planning, unsupervised learning, and reinforcement learning.

Robot Hardware:

Sensors:

Sensors are the perceptual interface between robot and environment.

Most ground robots are now equipped with **optical range finders** like scanning lidars(light detection and ranging), radar etc. On the other extreme end of range sensing are **tactile sensors** such as whiskers, bump panels, and touch-sensitive skin. These sensors measure range based on physical contact, and can be deployed only for sensing objects very close to the robot.

A second important class of sensors is **location sensors**. Most location sensors use range sensing as a primary component to determine location. Outdoors, the **Global Positioning System** (GPS) is the most common solution to the localization problem. GPS measures the distance to satellites that emit pulsed signals.

Indoors, localization is often achieved by attaching beacons in the environment at known locations. Many indoor environments are full of wireless base stations, which can help robots localize through the analysis of the wireless signal. Underwater, active sonar beacons can provide a sense of location.

The third important class is **proprioceptive sensors**, which inform the robot of its own motion. To measure the exact configuration of a robotic joint, motors are often equipped with **shaft decoders** that count the revolution of motors in small increments. On robot arms, shaft decoders can provide accurate information over any period of time. On mobile robots, shaft decoders that report wheel revolutions can be used for **odometry**—the measurement of distance traveled.

Other important aspects of robot state are measured by **force sensors** and **torque sensors**. These are indispensable when robots handle fragile objects or objects whose exact shape

and location is unknown. Imagine a one-ton robotic manipulator screwing in a light bulb. It would be all too easy to apply too much force and break the bulb. Force sensors allow the robot to sense how hard it is gripping the bulb, and torque sensors allow it to sense how hard it is turning.

Effectors

Effectors are the means by which robots move and change the shape of their bodies. To understand the design of effectors, it will help to talk about motion and shape in the abstract, using the concept of a **degree of freedom** (DOF). We count one degree of freedom for each independent direction in which a robot, or one of its effectors, can move. For example, a rigid mobile robot has six degrees of freedom, three for its (x, y, z) location in space and three for its angular orientation.

The effectors can be **revolute joints** that generates rotational motion and one **prismatic joints** that generates sliding motion.

Mobile robots have a range of mechanisms for locomotion, including wheels, tracks, and legs. **Differential drive** robots possess two independently actuated wheels (or tracks), one on each side, as on a military tank. If both wheels move at the same velocity, the robot moves on a straight line. An alternative is the **Synchro drive**, in which each wheel can move and turn around its own axis.

Sensors and effectors alone do not make a robot. A complete robot also needs a source of power to drive its effectors. The **electric motor** is the most popular mechanism for both manipulator actuation and locomotion, but **pneumatic actuation** using compressed gas and **hydraulic actuation** using pressurized fluids also have their application niches.

Localization

Localization is the problem of finding out where things are—including the robot itself. Knowledge about where things are is at the core of any successful physical interaction with the environment. For example, robot manipulators must know the location of objects they seek to manipulate; navigating robots must know where they are to find their way around.

Consider a mobile robot that moves slowly in a flat 2D world. Let us also assume the robot is given an exact map of the environment. The pose of such a mobile robot is defined by its two Cartesian coordinates with values x and y and its heading with value θ . If we arrange those three values in a vector, then any particular state is given by $\mathbf{X}_t = (x_t, y_t, \theta_t)$.

Motion Planning

All of a robot's deliberations ultimately come down to deciding how to move effectors.

The **point-to-point motion** problem is to deliver the robot or its end effector to a designated target location.

A greater challenge is the **compliant motion** problem, in which a robot moves while being in physical contact with an obstacle. An example of compliant motion is a robot manipulator that pushes a box across a table top.

Kinematics

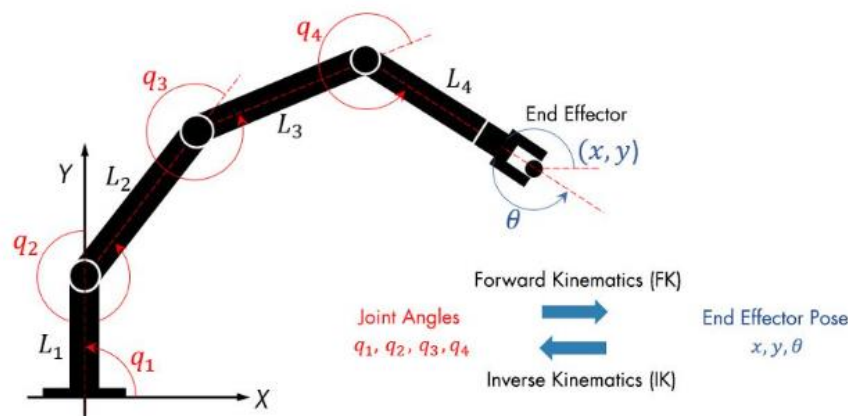
Kinematics studies the motion of bodies without consideration of the forces or moments that cause the motion. Robot kinematics refers the analytical study of the motion of a robot manipulator. Formulating the suitable kinematics models for a robot mechanism is very crucial for analyzing the behavior of industrial manipulators.

There are mainly two different spaces used in kinematics modelling of manipulators namely, **Cartesian space and Quaternion space**. The transformation between two Cartesian coordinate systems can be decomposed into a rotation and a translation. The quaternion space consists of quaternion numbers which is used for three dimensional rotations.

Kinematics describes the analytical relationship between the joint positions and the end-effector position and orientation.

Direct (also forward) kinematics – Given are joint relations (rotations, translations) for the robot arm. Task: What is the orientation and position of the end effector? Forward kinematics (for a robot arm) takes as input joint angles, and calculates the Cartesian position and orientation of the end effector.

Inverse kinematics – Given is desired end effector position and orientation. Task: What are the joint rotations and orientations to achieve this? Inverse kinematics takes as input the Cartesian end effector position and orientation, and calculates joint angles.



Configuring the joint positions of a robot using forward or inverse kinematics.

Machine Vision:

Machine vision (MV) is the application of computer vision to industry and manufacturing. Whereas computer vision is the general discipline of making computers see (understand what is perceived visually), machine vision, being an engineering discipline, is interested in digital input/output devices and computer networks to control other manufacturing equipment such as robotic arms and equipment to eject defective products.

Machine vision is the ability of a computer to "see." A machine-vision system employs one or more video cameras, analog-to-digital conversion (ADC), and digital signal processing (DSP). The resulting data goes to a computer or robot controller. **Machine vision is similar in complexity to voice recognition.** The machine vision systems use video cameras, robots or other devices, and computers to visually analyze an operation or activity. Typical uses include automated inspection, optical character recognition and other non-contact applications.

Two important specifications in any vision system are the sensitivity and the resolution. Sensitivity is the ability of a machine to see in dim light, or to detect weak impulses at invisible wavelengths. Resolution is the extent to which a machine can differentiate between objects. In general, the better the resolution, the more confined the field of vision. Sensitivity and resolution are interdependent. All other factors held constant, increasing the sensitivity reduces the resolution, and improving the resolution reduces the sensitivity.

One of the most common applications of Machine Vision is the inspection of manufactured goods such as semiconductor chips, automobiles, food and pharmaceuticals. Just as human, inspectors working on assembly lines visually inspect parts to judge the quality of workmanship, so machine vision systems use digital cameras, smart cameras and image processing software to perform similar inspections.

Machine vision systems have two primary hardware elements: the camera, which serves as the eyes of the system, and a computer video analyser. The recent rapid acceleration in the development of machine vision for industrial applications can be attributed to research in the areas of computer technologies. The first step in vision analysis is the conversion of analog pixel intensity data into digital format for processing. Next, an appropriate computer algorithm is employed to understand the image data and provide appropriate analysis or action.

Machine vision encompasses computer science, optics, mechanical engineering, and industrial automation. Unlike computer vision which is mainly focused on machine-based image processing, machine vision integrates image capture systems with digital input/output devices and computer networks to control manufacturing equipment such as robotic arms. Manufacturers favour machine vision systems for visual inspections that require high-speed, high-magnification, 24-hour operation, and/or repeatability of measurements.

A typical machine vision system will consist of most of the following components:

- One or more digital or analogue cameras (black-and-white or colour) with suitable optics for acquiring images, such as lenses to focus the desired field of view onto the image sensor and suitable, often very specialized, light sources
- Input/Output hardware (e.g. digital I/O) or communication links (e.g. network connection or RS-232) to report results
- A synchronizing sensor for part detection (often an optical or magnetic sensor) to trigger image acquisition and processing and some form of actuators to sort, route or reject defective parts
- A program to process images and detect relevant features.

The aim of a machine vision inspection system is typically to check the compliance of a test piece with certain requirements, such as prescribed dimensions, serial numbers, presence of components, etc. The complete task can frequently be subdivided into independent stages, each checking a specific criterion. These individual checks typically run according to the following model:

1. Image Capture
2. Image Preprocessing
3. Definition of one or more (manual) regions of interest
4. Segmentation of the objects
5. Computation of object features
6. Decision as to the correctness of the segmented objects

Naturally, capturing an image, possible several for moving processes, is a pre-requisite for analysing a scene. In many cases these images are not suited for immediate examination and require pre-processing to change certain sizing specific structures etc. In most cases it is at least approximately known which image areas have to be analysed, i.e. the location of a mark to be read or a component to be verified. These are called Regions of Interest (ROIs) (sometimes Area of Interest or AOIs). Of course, such a region can also comprise the entire image if required.

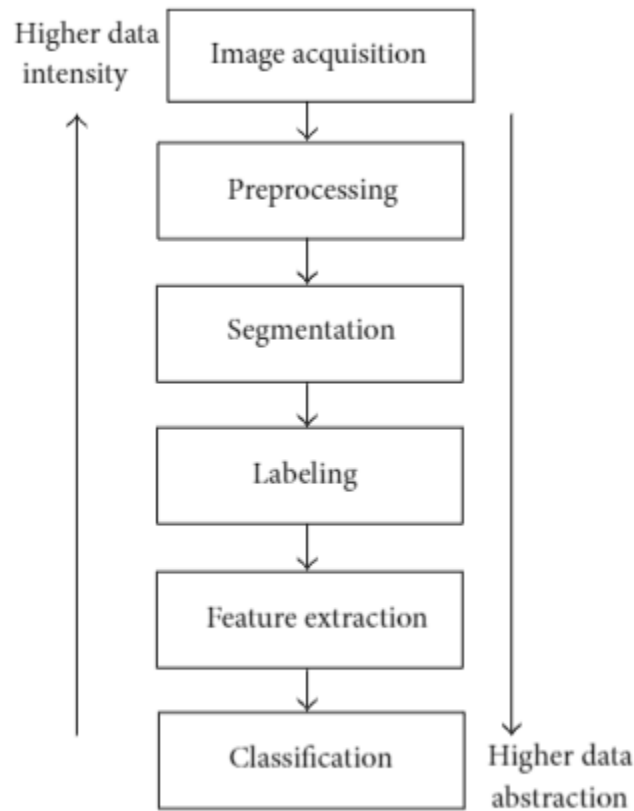


FIGURE 1: Fundamental steps of a machine vision system.

Machine vision is used in various industrial and medical applications. Examples include:

- Electronic component analysis
- Signature identification
- Optical character recognition
- Handwriting recognition
- Object recognition
- Pattern recognition
- Materials inspection
- Currency inspection
- Medical image analysis

Computer Vision:

Computer vision is the science and technology of machines that see, where *see* in this case means that the machine is able to extract information from an image that is necessary to solve some task. As a scientific discipline, computer vision is concerned with the theory behind artificial systems that extract information from images. The image data can take many forms, such as video sequences, views from multiple cameras, or multi-dimensional data from a medical scanner.

As a technological discipline, computer vision seeks to apply its theories and models to the construction of computer vision systems. Examples of applications of computer vision include systems for:

- Controlling processes (e.g., an industrial robot or an autonomous vehicle).
- Detecting events (e.g., for visual surveillance or people counting).
- Organizing information (e.g., for indexing databases of images and image sequences).
- Modeling objects or environments (e.g., industrial inspection, medical image analysis or topographical modeling).
- Interaction (e.g., as the input to a device for computer-human interaction).

Computer vision is closely related to the study of biological vision. The field of biological vision studies and models the physiological processes behind visual perception in humans and other animals. Computer vision, on the other hand, studies and describes the processes implemented in software and hardware behind artificial vision systems. Interdisciplinary exchange between biological and computer vision has proven fruitful for both fields.

Computer vision is, in some ways, the inverse of computer graphics. While computer graphics produces image data from 3D models, computer vision often produces 3D models from image data. There is also a trend towards a combination of the two disciplines, e.g., as explored in augmented reality.

Sub-domains of computer vision include scene reconstruction, event detection, video tracking, object recognition, learning, indexing, motion estimation, and image restoration.

AI in Data Science