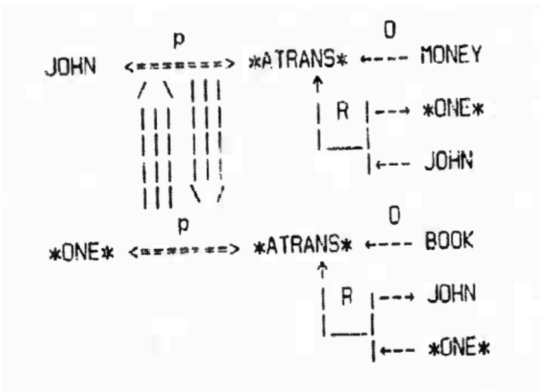
Inference and the computer understanding of natural language. Roger C. Schank & Charles J. Rieger III

I. Introduction

- for a system that understands natural language it is necessary to differentiate between the domains of parsing and inference
- Conceptual Dependency Theory
- inference: a new piece of information which is generated from other pieces of information, and which may or may not be true
    - the intent of inference making is to "fill out" a situation: feasibility, causality and intent of the utterance
- inference vs deduction
    - one of the definitions of processing conceptual input (a "reflex response") is the generation of inferences from it
    - an inference is not necessarily a logically valid deduction
    - an inference is not necessarily true (memory must be willing and able to respond to contradictions)
    - motivation: formal deductions have a well-defined goal, axioms and theorems to help achieve it; inferences are used differently ("to see what they can see")
    - memory needs to remember why a piece of information exists (in case it has to alter the credibility of a piece of information when the credibility of some piece of information which was used in its generation changes)

II. Inference and parsing

- the desired output for a conceptual analyser is a meaning representation
- since it is possible to go directly from an input sentence into a meaning representation, we disregard any discussion of syntactic parsing output
- a meaning representation should contain every concept and conceptual relation that is explicitly or implicitly referred to by the sentence
    - "John bought a book."
    - explicit: the concepts that underlie a given word ('John', 'book')
    - implicit: 'bought' references two actions of transfer (book, money)
- parsing: the extraction of explicit and implicit information
- inference: the adding-on of probably correct information
- an instance of linguistic inference exists when, in the absence of specific information to the contrary, a given word or syntactic construction can be taken to mean that a specific but unmentioned object is present in a predicted case for a given ACT with a likelihood of near certainty (e.g. 'buy' as an abstract transfer action (ATRANS) probably includes an object, a recipient and a donor)
- so "John bought a book" looks something like this:



< = > denotes the relation between actor and action
< -- O denotes the relation between action and object
< ≡ denotes causality dependence
R | -- >
< --- |
| < -- denotes the relation between action, object, recipient and donor)

III. The 14 primitive actions

- 6 conceptual categories in Conceptual Dependency:
  - PP real world objects
  - ACT real worlds actions
  - PA attributes of objects
  - AA attributes of actions
  - T times
  - LOC locations
- syntactic rules of conceptualizations (not a full list):

```
PP <=> ACT        indicates that an actor acted

PP <≡> PA         indicates that an object is in a given state

      O
ACT <---  PP      indicates the object of an action

     R |--> PP
ACT <--|          indicates the recipient and the donor of an
       |<-- PP    object within an action

     D |--> PP
ACT <--|          indicates the direction of an object within
       |<-- PP    an action

      I  /\
ACT <--- ||       indicates the instrumental conceptualization
         \/       for an action
   X
  / \
  |||             indicates that conceptualization X caused
  |||             conceptualization Y. When written with a "c",
   Y              this form denotes that X COULD cause Y.

      |--> PA2
PP <≡|            indicates a state change of an object
      |<-- PA1

PP1 <-- PP2       indicates that PP2 is either PART OF or the
                  POSSESSOR OF PP1
```

- tenses are considered to be modifications of the main link between actor and action (<=>), or the link between an object and its state (<≡>)
- main link modifiers:
  - p past
  - f future
  - (null) present
  - ts=x begin a relation at time x
  - tf=x end a relation at time x
  - c conditional
  - / negation
  - ? question
- the 14 ACTs:
  - ATRANS: the transfer of an abstract relationship; PTRANS: the transfer of physical location of an object; PROPEL: the application of a physical force to an object; MOVE; GRASP; INGEST; EXPEL; MTRANS: the transfer of mental information (memory partitioned into: CP conscious processor, LTM long-term memory, and sense organs); CONC: the conceptualizing or thinking

about an idea; MBUILD: the construction of new information from old information; SMELL; SPEAK; LOOK-AT; LISTEN-TO

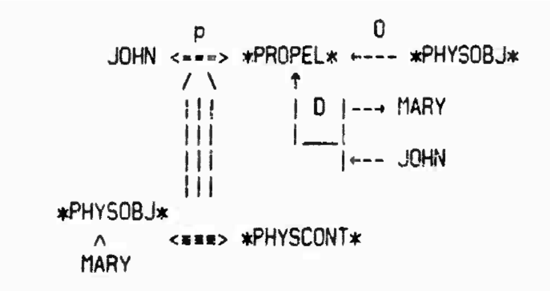
- rules used within Conceptual Dependency:
    - there are 4 conceptual cases: objective, recipient, directive, instrumental
    - each ACT takes from two to three of these cases obligatorily and none optionally
    - instrumental case is itself a complete conceptualization involving an ACT and its cases
    - only animate objects may serve as actors except for PROPEL

IV. Language-free inferences

- an instance of act-inference is present when an actor and an object occur in a conceptualization without an ACT to connect them, and the object in question has a normal function in the world. In this case the normal function is assumed to be the implicitly referenced ACT
- a trans-enable-inference occurs with a conceptualization involving one of the TRANS ACTs. It is inferred that the TRANS conceptualization enables another conceptualization involving the same actor and object to take place. The specific act for this inferred conceptualization then comes about via act-inference. Inferences of this type are frequently useful for inferring the intended use of a physical or mental object.
    - “John likes chocolate” i.e. John likes ingesting chocolate/if John ingests chocolate, he is happy
- result-inference can be made whenever a TRANS ACT is present and no information exists that would contradict the inferred result
    - unless stated otherwise, “John went to South Dakota” is true (it happened)
- an instance of object-affect-inference may be present with any of the physical ACTs (INGEST, EXPEL, PROPEL, GRASP, MOVE). The certainty of any of these inferences is dependent of the particular ACT. When object-affect-inference is present, a new resultant physical state is understood as having been caused by the given ACT
    - “John ate an egg” – the egg ceased to exist
- an instance of belief-pattern-inference exists if the given event plus its inferred results fits a belief pattern that has in it the reason for that kind of action under ordinary circumstances
    - “Mary is angry at John” – possibly because John did something to make her angry
- instrumental-inference can always be made, although the degree of accuracy differs depending on the particular ACT. Whenever an ACT has been referenced, its probable instrument can be inferred.
    - “John received the ball” – PTRANS ACT, the ball was either moved or propelled at him
- whenever an object is introduced in a sentence certain subpropositions are being made, the most common is the predication that the object being referenced exists. The inference of these subpropositions we call property-inference
    - “John caught the ball” – John exists, a ball exists, John has arms
- an instance of sequential-inference is potentially present when one sentence follows another and they share a subject or a proposition. When subpropositions or inferences of subpropositions can be detected as common to both conceptualizations, and satisfy certain set inclusion or contradiction rules, sequential-inference may apply.
- an instance of causality-inference is present if two sentences are connected by an ‘and’ or by their appearing in sequence. Then if one could have caused the other, it can be inferred that that is what happened
    - “Mary hugged John and he started crying.”
- all conceptualizations are potentially subject to backward-inference. Depending on the nature of the object, one of the TRANS ACTs can be inferred as having enabled the current conceptualization’s occurrence
    - “John ate a banana” – at some point he bought one

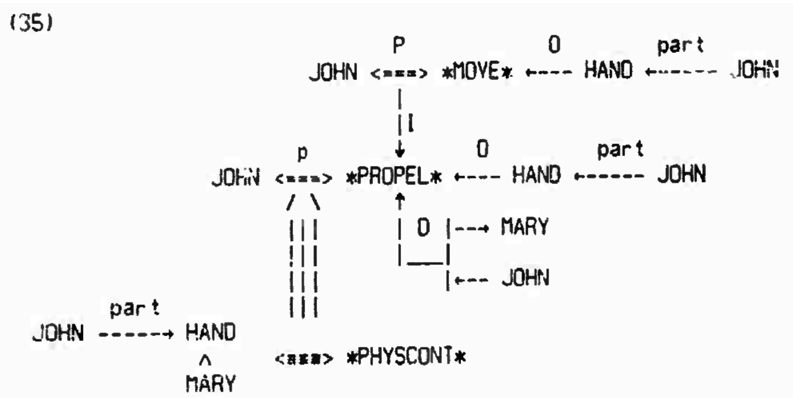
- intention-inference is assumed whenever an actor acts unless information to the contrary exists
    - “John ate a banana” – because he wanted to, it was his intention to do so

V. Observations



“John hit Mary.”

- the following inferences are needed:
    - linguistic: add ‘hand’ as object of PROPEL
    - object affect: add causal ‘recipient (Mary) be hurt’
    - belief pattern: add potential cause as Mary DO cause John be hurt cause John be angry
    - instrumental: add instrument of MOVE ‘hand’
    - property: add predication that Mary and John exist, John has hands, they were in the same place at the same time
    - intention: add that John wanted to hit Mary



VI. The program

- memory’s data structures and goals
    - all propositional information is stored in list positional notation, with the predicate first and the conceptual case slots following
    - bond: the internally stored form of a proposition (stored as a single superatom)
    - propositions are easily embedded, and look like simple concepts (except for their bond)
    - simple concepts have an occurrence set to define them
    - the occurrence set is a set of pointers to superatoms which contain instances of the simple concept
- superatoms’ characteristics: strength (credibility), mode (true or false), truth (true if the proposition is true in the world at present time), reasons (the set of superatoms which participated in the generation of this proposition i.e. what facts were used to infer this proposition), offspring (reasons’ inverse), recency (the value of the system clock when the superatom or concept is accessed)
- inferences are organized as lambda functions under predicates, and are invoked directly by conceptualizations
- the program performs the following tasks:
    - establish referents of all concepts

    - serve as a passive data bank and access mechanism for the analysis and generation phases
    - store the analysed contents of each sentence
    - perform appropriateness checking on all peripheral implications of an input
    - generate inferences and elevate some of them to the status of predictions (prediction being an inference the system has chosen to focus on):
        - completatory (supplies a most likely candidate for some missing information)
        - causal (try to relate the input to belief patterns which could explain the reasons behind the input)
        - result (establish possible outcomes caused by the input)
    - maintain a record of inferencing and prediction activity
    - answer wh-type questions concerning the conceptualizations and their inferences
    - + a forgetting function
- going back to “John hit Mark”
- the analyser parses descriptive sets to memory: sets of conceptual propositions which memory can use to identify the actual referent of the concept described
    - Cn: {(P1) … (Pk)} denotes some concept having descriptive propositions P1 … Pk; also memory is not yet familiar with this concept
    - #<word> stands for the unique concept which “<word>” references

```
( (CAUSE ( (PROPEL      C1 : { (ISA _ #PERSON) (NAME _ “JOHN“) }
                        C2: { (ISA _ #HAND) (PART _ C1)
                        C1
                        C3: { (ISA _ #PERSON) (NAME _ “MARK“) }
            ) )
            ( (PHYSCONT C2 C3) )
    ) TIME _ C4 : { (ISA _ #TIME) (BEFORE _ #NCW) } )
  )
```

- memory establishes the referents, then:

```
( (CAUSE ( (PROPEL #JOHN #C0001 #JOHN #MARK) )
            ( (PHYSCONT #C0001 #MARK) )
(TIME _ #C0002) )
```

- next, memory fragments the conceptualization into subpropositions
- a subproposition is any unit of information which is conveyed directly by a conceptualization; explicit (focussed and peripheral) and implicit subpropositions
    1. John propelled something.
    2. A hand was propelled.
    3. John moved something.
    4. A hand was moved.
    5. A hand is part of John.
    6. Something was propelled from John to Mark.
    7. A hand and Mark were in physical contact.
    8. John propelled his hand.
    9. 8 caused 7.
    10. It was before “now” that 1-9 occurred.
- next (the physical and intentional components are distinct, they proceed in parallel):

```
( (MLOC ( (CANCAUSE    ( (NEGCHANGE #MARK #PSTATE) )
                       ( (POSCHANGE #JOHN #JOY) ) ) )
            #C0003)
(TIME _ #C0002) )
                       (#C0003 is John’s LTM)
```

- a prediction: when a person is hurt, they want to get better
  ((MLOC ((CANCAUSE ((POSCHANGE #MARK #HEALTH))
  ((POSCHANGE #MARK #JOY))))
  #C0004)
  (TIME _ #C0005))
  #C0004 is Mark's LTM,
  #C0005 is (AFTER C0002)
- Mark's likely actions are predicted:
  ((CANCAUSE ((INGEST #PERSON #MEDICINE))
  ((POSCHANGE #PERSON #HEALTH))))
- and here the inference is stopped (another option: John hit Mark because Mark made John angry)
  ((PREDICTIONSET #MARK
  ((INGEST #MARK #MEDICINE #UNSPEC #C0006))
  ((PTRANS #MARK #MARK #UNSPEC #C0007))))
  where C0006 is Mark's INSIDES,
  C0007 is a token of a #HOSPITAL

- memory has taken the conceptual analysis underlying an English sentence and generated new probabilistic information from it in an attempt to relate it to knowledge memory may already have stored
- the new information took three basic forms
  1. predictions about the causes of the input
  2. predictions about the possible results of the input
  3. predictions about future and past actions of people