MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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Rete; Language and Mind

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Agenda

1. **Administrivia**
2. **Rete, rete**
3. **Language: Why language is special; from Words to Meaning**
4. **Syntactic nets to semantic nets**
5. **The Blue Room: The Language of Thought?**

1. **Administrivia: lunch?**
2. **Rete. Key ideas:**

- If-then forward chaining rules can be reorganized for efficient pattern matching.
- The RETE algorithm creates a decision tree that combines the patterns in all the rules of the knowledge base.
- Once it has been determined which patterns have been matched by facts, comparisons of variable bindings across patterns must be checked in a relational database table that 'remembers' what partial matches have already been tested.
- The **key** to its efficiency is AWP again: to do partial (incremental) matching - it remembers past test results across iterations of the rule matching loop. Only new facts are tested.
- **Variable bindings are saved and reused, rather than recompjuted.**

Recall that we talked about **forward chaining**as a procedure that loops through a set of rules, searching a database of assertions for variable bindings that match rule antecedents. When matches are found, rules are triggered and fired, producing no assertions (or removing assertions). When new assertions are added, the loop through a rule set repeats. The Rete algorithm takes advantage of two observations: (1) not many assertions are added or changed when a rule fires, and the changed assertions do not affect many rules; and (2) many rules share antecedents (i.e., their 'if' components are similar). The disadvantage of Rete is: it takes memory to store all these pre-recorded variable bindings/matches, and we must expend effort to remove (failed) match information.

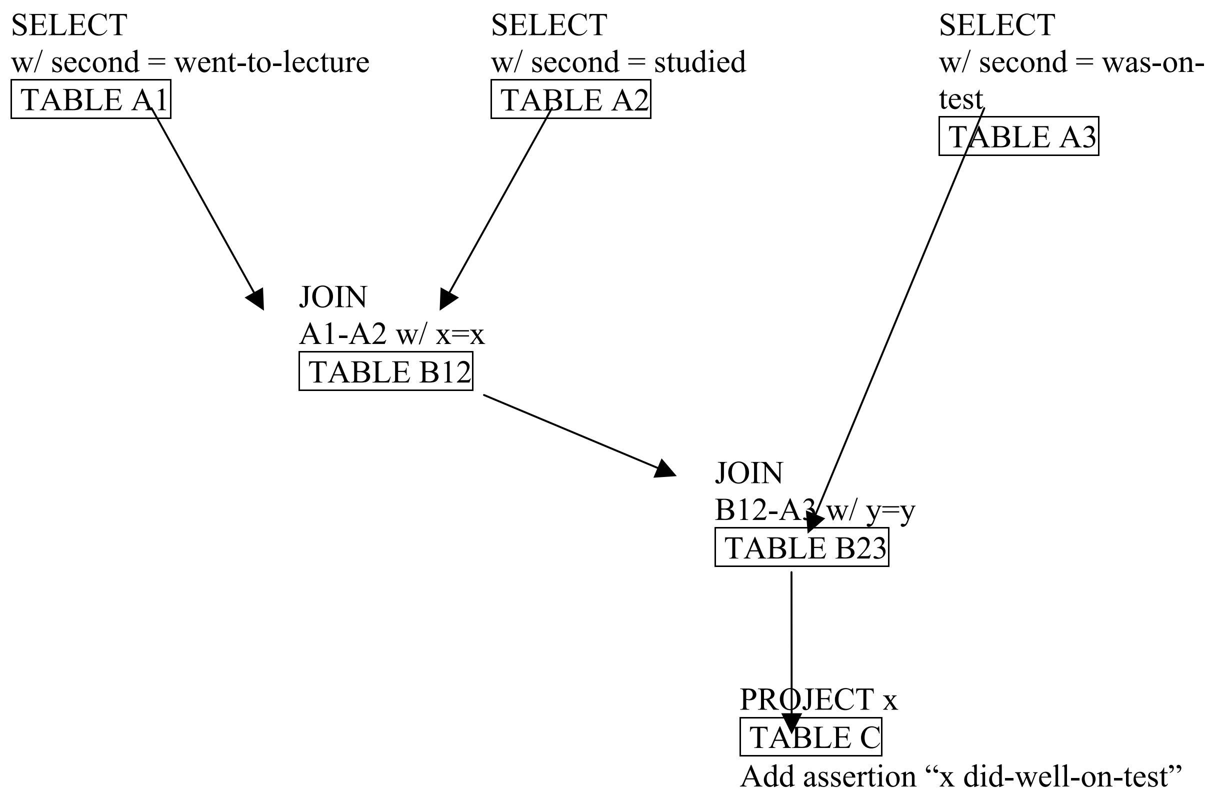
Each node in a Rete network (graph) represents the set of variable bindings that match an assertion or a collection of assertions. The Rete algorithm works by moving assertions through the graph, like a pinball machine, saving incremental match information as it goes. A **path through the graph to a leaf represents the bindings that match the antecedents to a rule** (take a look below). You can think of the root node as a node that connects subgraphs for all antecedents of a particular length (which is why we can use relational databases to implement them – each node, except the root node, is a **table** representing one relation, and each **row** of the table records one assertions. The match procedure uses a database **select** operation to define the match, then a **project** operation to find specific matches in the set of all assertions. To collect all antecedents, we use a (sequence of) database **join** operations, with a final execute action that is a database **project** to get the subset of all matching variables needed for the consequent.)

To build a rete:

- For each antecedent, create an 'alpha' node, aka a 'match' node (these are the root nodes)
- Join a first antecedent and a second antecedent to create a 'beta' node, aka a 'merge' node
- Join each subsequent antecedent with the previous merge node to create a new merge node
- For each consequence, create a terminal node, aka **execute** node, via **project**, that carries the consequent.

The Rete algorithm keeps up to date the information associated with the nodes in the graph. When a fact is added or removed from working memory, a token representing that fact and operation is entered at the root of the graph and propagated to its leaves modifying as appropriate the information associated with the nodes. When a fact is modified, say, the age of John is changed from 20 to 21, this is expressed as a deletion of the old fact (the age of John is 20) and the addition of a new fact (the age of John is 21).

RULE:		**ASSERTIONS:**
IF	**(?x went-to-lecture)**	**You went-to-lecture**
	(?x studied ?y)	**You studied nothing**
	(?y was-on-test)	**Nothing was-on-test**
THEN	**(?x did-well-on-test)**	



3. Language: Why language is special; from Word strings to Meaning (Syntax to semantics)

Language is special: The Twain Test (Unsupervised learning; very small sample complexity – 1-5 examples; no Wall Street Journal subscriptions), and "the Burst Effect". At age 1 yr, 1-11 months or so, these are the kinds of utterances children produce:

Ride papa's neck; this my rock-baby; mama forget this

By the age of 3, this is what they produce. What's the difference?

You match me open sandbox; Papa, you like this song? I won't cry if mama wash my hair

The same difference shows up in this way.
Pop-quiz (multiple choice): who produced the following 'sentences' (Names changed to protect the innocent):

(1) I see red one (2) P. want drink (3) P. open door (4) P. tickle S. (5) I go beach (6) P. forget this (7) P said no (8) P. want out (9) You play chicken

Multiple choice: (a) Pidgin speakers; (b) apes (signing); (c) Feral child Genie; (d) ordinary children [Hint: recall the Burst effect plus the general rule about tricky 6.034 questions]

Question: How can we *represent* knowledge of language? How can we *compute* with it? (Like data structure + algorithm question). Answer to first part (representation) – this is what linguists do for a living. What are the *underlying representations* that constitute our knowledge of language? Answer to the second part (computation) – this is what syntactic and semantic transition trees partially accomplish, mapping strings of words into procedural operations on a database ("meaning").

As to the first part, look at how much we implicitly 'know' about a language. Take even a simple sentence like *the cats ate ice-cream.*

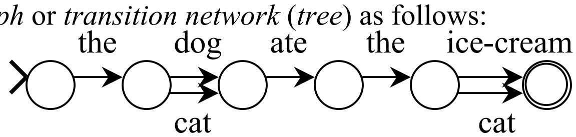
- We know how each word sounds and whether it's an English word at all. *Ca* begins a valid English word, but no English word will start out *ptk* (but could in Polish). Further, the *s* on *cats* marks it as plural.
- We know that the words must appear in a certain order. *Ice-cream ate the cats* means something very different from *The cats ate the ice-cream.*
- We know "who did what to whom," a kind of mental snapshot: *the cats* is the agent of the action *ate* while *the ice-cream* is the thing eaten, or the affected object. (These are the *thematic roles* or *slots in a thematic role frame*) . And so on…

It is conventional to divide the study of the representation of linguistic knowledge into two parts: syntax, the study of word arrangements without regard for meaning – this derived from the Greek word *syntaxis*, literally 'to arrange together' and semantics, the study of meaning.

Syntax determines the allowable combinations of primitives in a language, where one notion of primitives are word categories, and further, combinations of word categories. For example, let us suppose that we had sentences like these:

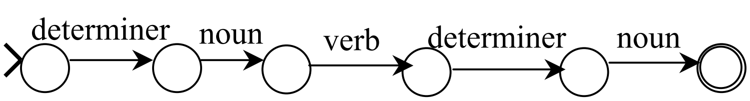
The cat ate the ice-cream
The dog ate the ice-cream
The dog ate the cat

If we take these words for the moment as primitives, we can simply write down these possible linear patterns as a *directed graph* or *transition network* (*tree*) as follows:



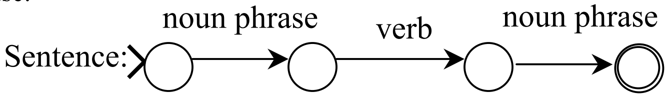
Here, the 'start' state is marked by an incoming arrow, and the final (goal) state is a double circle. Given a transition network and a string of words (a sentence), we can *check* to see if the string of words can be 'let through' the network, or *generated* by it. To do this, we start by looking at the first word in the sentence can let us move from one state to the next via a *transition* – does the label on the arc match the current word in the sentence we are looking at? (See how we can march through the first example sentence this way. If we arrive at the end of the sentence and are in the goal state, we win.)

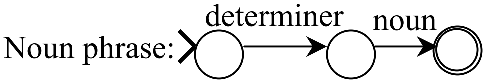
Of course, it would get very boring (and wrong) to just keep writing down words as arc labels to encompass more and more sentence patterns: *a dog ate the ice-cream; a cat ate the ice-cream; a dog ate the cat; the dog ate an ice-cream;* etc. Instead, we can *collapse* collections of words such as {dog, cat, ice-cream, tree,…} into a *word category* called 'Nouns' and words like {a, the, an…} into a category called 'Determiners' (because they 'determine' in some sense the multiplicity of the Noun that comes later). That gives us the following, more compact network:



Of course, now this transition tree (network) will allow some 'funny' word sequences – but we did say this was *syntax,* not semantics. Only form matters.

Finally, since we are good programmers, we notice a final redundancy in the network: the pattern "determiner noun" is repeated, once as the 'Subject' of the sentence, and once as the 'Object'. So, why not turn that pattern into a subroutine? We can call the repeated pattern a 'Noun Phrase' and splice out the repeated pattern (see the network below.) Of course, since this is a subroutine, we must have a way to *call* and *return* from subroutines generally (i.e., we must use a *stack* and sentences are now *recursive*). Now we will have two networks: the main Sentence network and a 'subnetwork' called a Noun Phrase. We need a new label in the Sentence network that is called 'Noun Phrase', and marking that at the beginning of a valid sentence, we must find a Noun Phrase:





We now have that in English, a Sentence 'is a' Noun Phrase followed by a Verb and then a Noun Phrase. (This of course is not always so!) We can further combine a Verb and a Noun phrase into a unit called a Verb Phrase. This is what a syntactic transition network can easily encode. We just replace 'isa' and map the 'followed by' with a graphical representation:

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Sentence 'is a'  Noun Phrase  Verb Phrase
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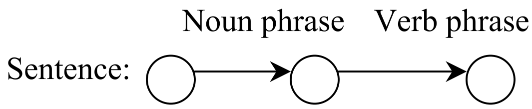

How would we modify this to handle an example like "John slept"?

So far, our *syntactic* networks merely check the *form* of sentences. They don't *do* anything. We can couple form (syntax) to actions by adding procedures that trigger as each arc is traversed or as we hit the end of a network (or both). Such actions *translate* the input sentence into a series of actions, often a series of database calls, just as a compiler will parse a line of program code and output the actual sequence of machine instructions to be followed. In the case of computer code, the "meaning" simply *is* the sequence of machine instructions; in the case of a simple natural language system, the "meaning" is the database calls; in general, the "meaning" of a sentence is much more complicated than that. As a simple example, though, following the Winston notes, consider a sentence like "How many screwdrivers are there?" The goal of the network is to map the query into a set of database and procedure calls. As we traverse the portion of the network corresponding to "How many", we output "Count" (a procedure call). As we traverse "screwdrivers are there" we output a database call that 'selects' the screwdrivers and returns a list of them (or, if we are using a real database program, most likely the count routine would be built in and we could do it all at once.) The key idea, though is this:

Distinct paths through the network represent distinct meanings= distinct procedure and database sequence calls

Example: *Fruit flies like a banana*. Or, *I saw an elephant in my pajamas* There are at least 2 obvious paths (in an expanded network) hence 2 meanings:

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 Fruit    flies     like      a          banana
 Noun     Verb     Adverb    Determiner   Noun
Adjective Noun      Verb     Determiner   Noun
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(For a more complex example, consider, "I saw the cat that Sue said died yesterday".)

To summarize, syntax links the arrangement of words to meaning, "semantics," which we define as the action carried out at the end of a network. So, syntax matters to language. Winston ate the spider has a very different meaning from The spider ate Winston (at least, it matters to Winston). But semantics matters too: we can say "Winston admires sincerity" but not "Sincerity admires Winston". ('Admire' requires an animate subject).

4. From Syntactic nets to Semantic nets

It's now simple to move on to *semantic transition trees* (networks). All you do is replace the purely *syntactic* categories like Noun, Verb, Determiner with *semantically meaningful* categories like 'tool,' 'color,' 'size,' etc. Everything else remains as before. What is the advantage? You are translating more immediately and directly into semantic actions, instead of routing everything first into a syntactic form. What is the disadvantage? A lack of modularity; how do we tell what the right categories are for a domain? What happens when we switch domains?

5. The Blue Room: The language of thought?

Spelke's experiment & the Burst Effect. Recall the Spelke experiment: rats and adults/older children in a room. Task: locate reward hidden in one of 4 corners of a room; reward is hidden in their sight; Subjects are then blindfolded & spun around (like pin the tail on the donkey) to disorient. Then remove blindfold and see how quickly they can locate the reward

- Puzzle 1: first room setup, people and rats did fine and headed straight for the hidden reward. Why?
- Once that effect was controlled for, then test effect of having strong cue, like one wall being BLUE
- Results: now, only adults and syntactically capable children succeed. Why?

Transition networks/Semantic nets

Use the transition-net grammar on the problem sheet to find two different ways of parsing this sentence:
"The car hit the old man with the cane." (two parses= two paths through the net = two different 'meaings'), or 'ambiguity'

1. **Food for thought:** What would we have to do to accommodate new sentence forms such as, "Which boy saw the car"? What does this sentence **mean**? What would happen if we changed the language to Japanese? German? Russian? Warlpiri? What would happen if we change the 'semantic' domain? (For a semantic transition tree) What would happen if we changed the language to Japanese, German, Russian,…. How do we know what 'semantic' categories to use?
2. What aspects of human language does this not seem to capture?