CS626: Speech, NLP and the Web

Model Theoretic Semantics, Pragmatics

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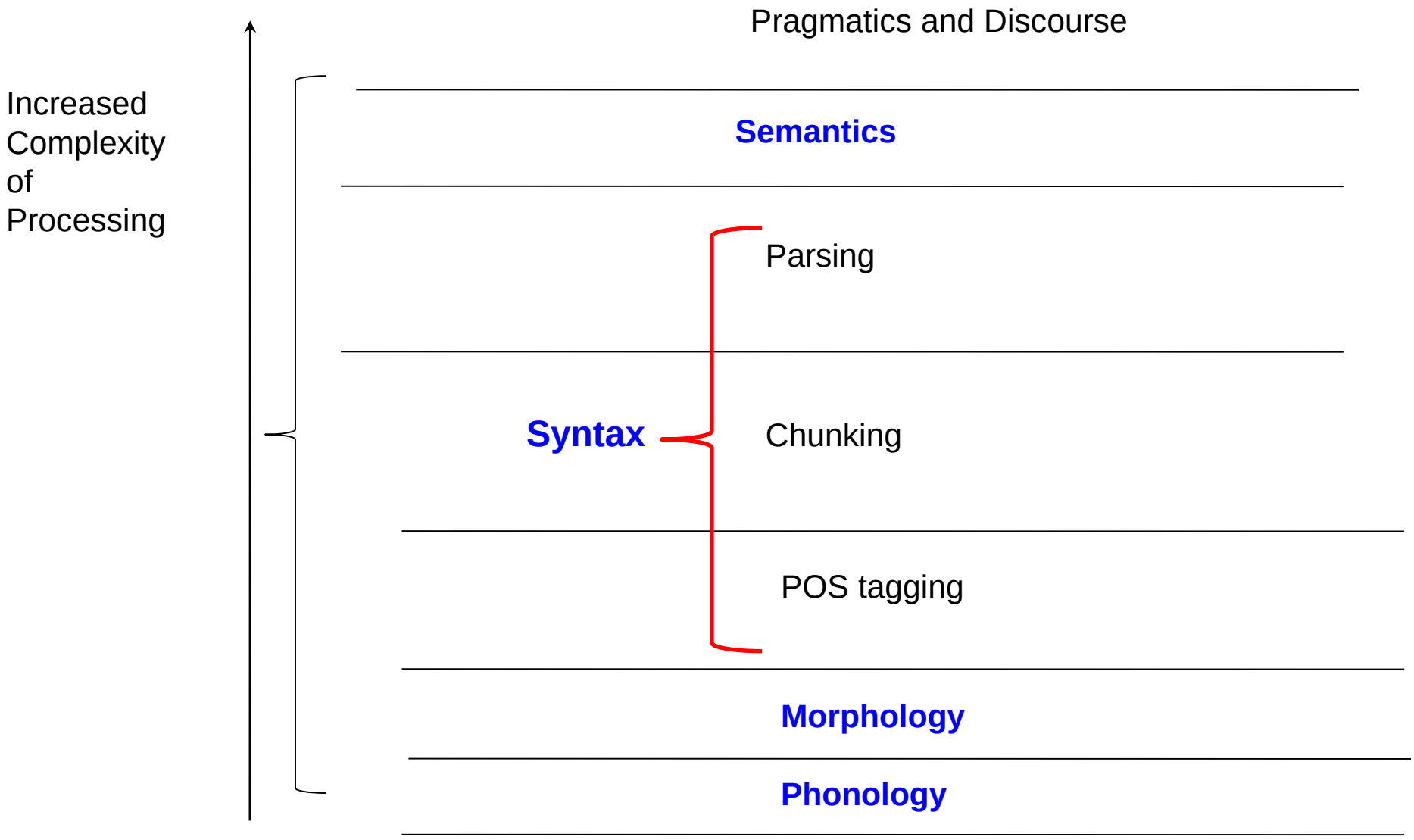
NLP (and linguistics) Layers



Model Theoretic Semantics

Domain of Discourse, Predicate Calculus

Himalayan Club example

- Introduction through an example *(Zohar Manna, 1974):*
  - Problem: A, B and C belong to the Himalayan club. Every member in the club is either a mountain climber or a skier or both. A likes whatever B dislikes and dislikes whatever B likes. A likes rain and snow. No mountain climber likes rain. Every skier likes snow. *Is there a member who is a mountain climber and not a skier?*
- Given knowledge has:
  - Facts
  - Rules

Example contd.

- Let *mc* denote mountain climber and *sk* denotes skier. Knowledge representation in the given problem is as follows:
  1. *member(A)*
  2. *member(B)*
  3. *member(C)*
  4. *∀x[member(x) → (mc(x) ∨ sk(x))]*
  5. *∀x[mc(x) → ~like(x,rain)]*
  6. *∀x[sk(x) → like(x, snow)]*
  7. *∀x[like(B, x) → ~like(A, x)]*
  8. *∀x[~like(B, x) → like(A, x)]*
  9. *like(A, rain)*
  10. *like(A, snow)*
  11. *Question: ∃x[member(x) ∧ mc(x) ∧ ~sk(x)]*
- We have to infer the 11th expression from the given 10.
- Done through Resolution Refutation.

Club example: Inferencing

1. $member(A)$
2. $member(B)$
3. $member(C)$
4. $\forall x[member(x) \rightarrow (mc(x) \vee sk(x))]$
   - Can be written as
   - $[member(x) \rightarrow (mc(x) \vee sk(x))]$
   - $\sim member(x) \vee mc(x) \vee sk(x)$
5. $\forall x[sk(x) \rightarrow lk(x, snow)]$
   - $\sim sk(x) \vee lk(x, snow)$
6. $\forall x[mc(x) \rightarrow \sim lk(x, rain)]$
   - $\sim mc(x) \vee \sim lk(x, rain)$
7. $\forall x[like(A, x) \rightarrow \sim lk(B, x)]$
   - $\sim like(A, x) \vee \sim lk(B, x)$

8. $\forall x[\sim lk(A,x) \rightarrow lk(B,x)]$

– $lk(A,x) \vee lk(B,x)$

9. $lk(A,rain)$

10. $lk(A,snow)$

– Negate–

$\exists x[member(x) \wedge mc(x) \wedge \sim sk(x)]$

$\forall x[\sim member(x) \vee \sim mc(x) \vee sk(x)]$

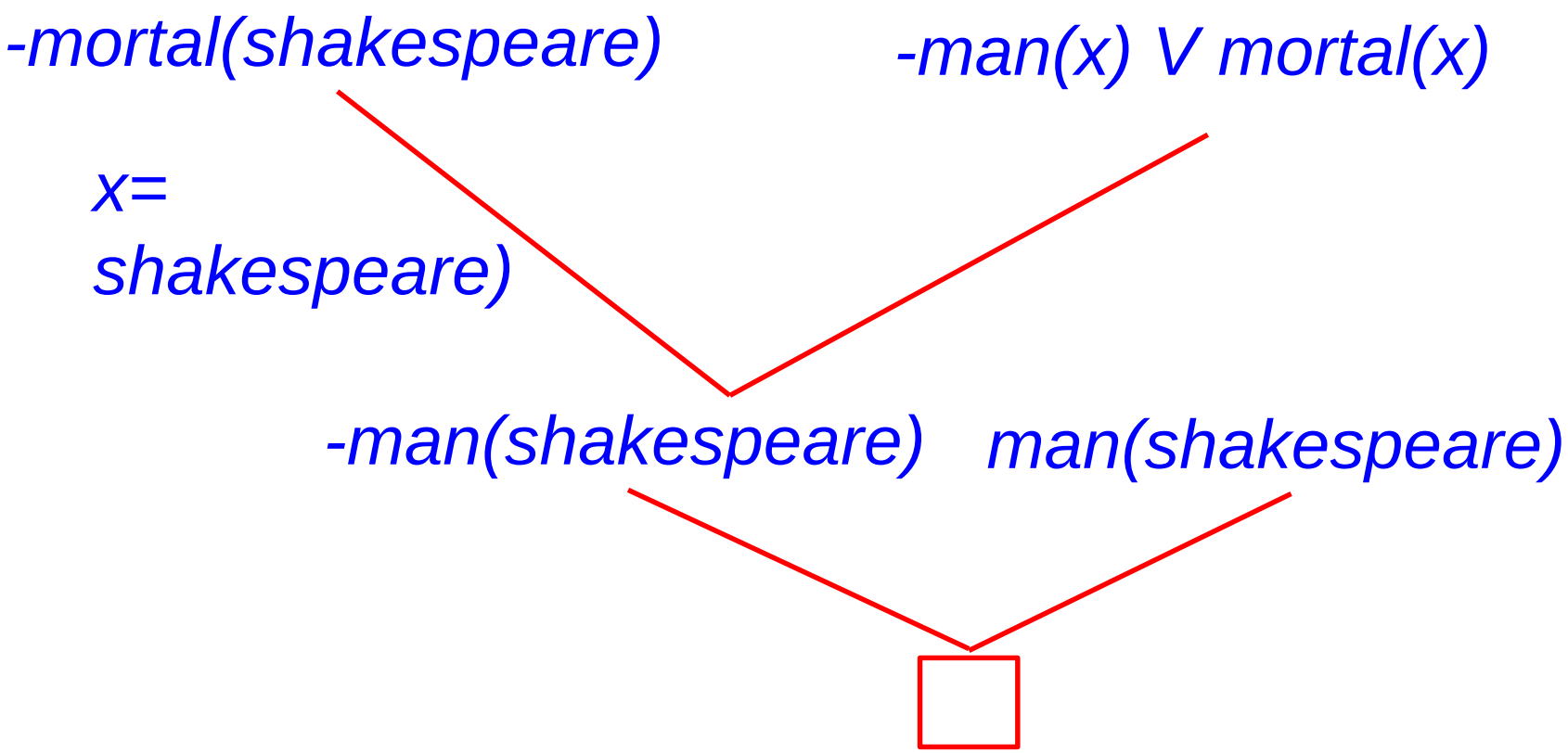
- Now standardize the variables apart which results in the following

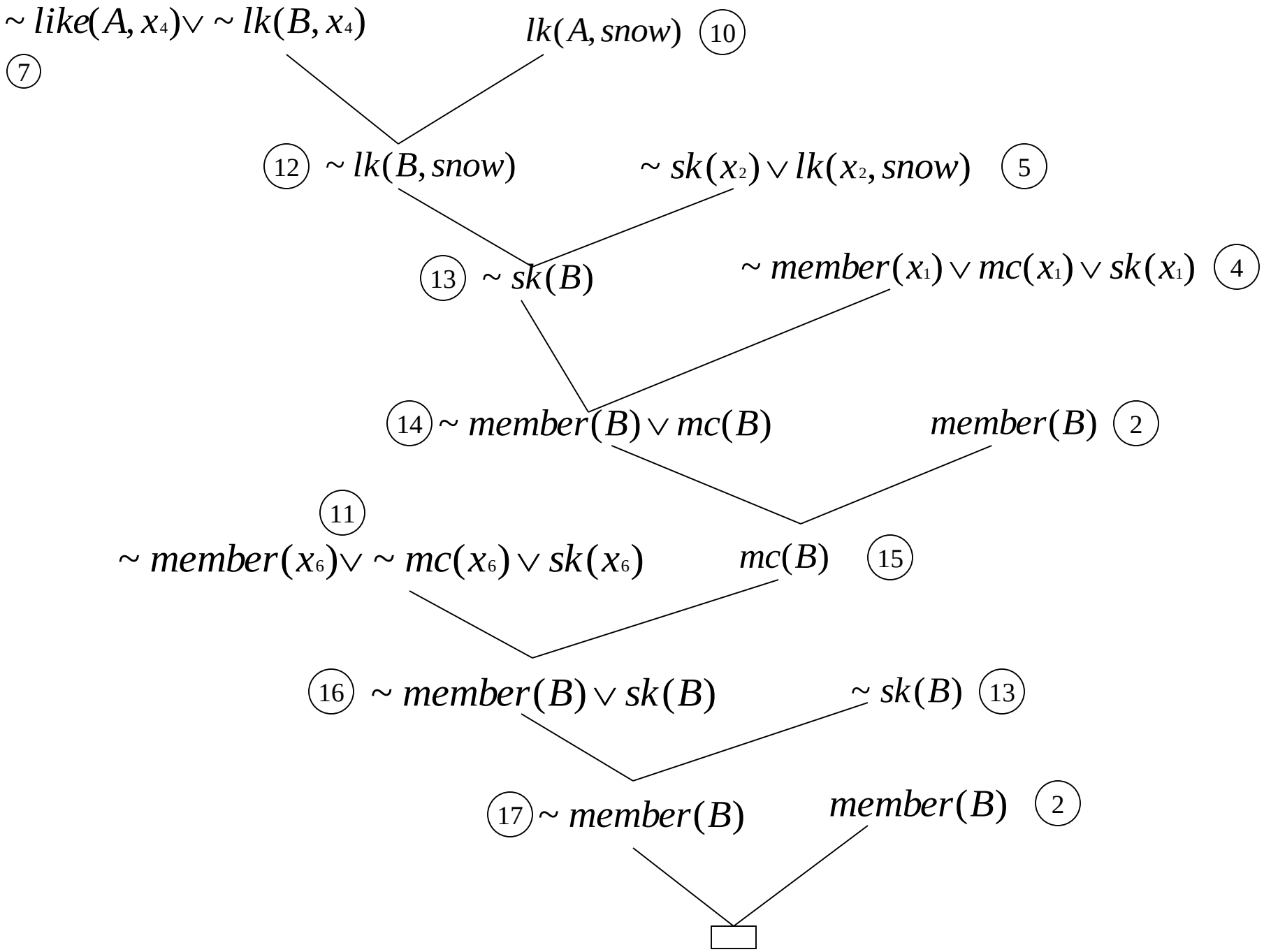
1. $member(A)$
2. $member(B)$
3. $member(C)$
4. $\sim member(x_1) \vee mc(x_1) \vee sk(x_1)$
5. $\sim sk(x_2) \vee lk(x_2, snow)$
6. $\sim mc(x_3) \vee \sim lk(x_3, rain)$
7. $\sim like(A, x_4) \vee \sim lk(B, x_4)$
8. $lk(A, x_5) \vee lk(B, x_5)$
9. $lk(A, rain)$
10. $lk(A, snow)$
11. $\sim member(x_6) \vee \sim mc(x_6) \vee sk(x_6)$

Resolution-Refutation (the how of it)

man(x) → *mortal(x)*, equivalent to

~man(x) V mortal(x)




~ like(A, x4) ∨ ~ lk(B, x4)
7
lk(A, snow)
10
12
~ lk(B, snow)
~ sk(x2) ∨ lk(x2, snow)
5
13
~ sk(B)
~ member(x1) ∨ mc(x1) ∨ sk(x1)
4
14
~ member(B) ∨ mc(B)
member(B)
2
11
~ member(x6) ∨ ~ mc(x6) ∨ sk(x6)
mc(B)
15
16
~ member(B) ∨ sk(B)
~ sk(B)
13
17
~ member(B)
member(B)
2

Well known examples in Semantics expressed in Predicate Calculus

- Man is mortal : rule

  $\forall x[man(x) \rightarrow mortal(x)]$

- shakespeare is a man
  man(shakespeare)

- To infer shakespeare is mortal
  mortal(shakespeare)

Model Theoretic Semantics: PC primitive: N-ary Predicate

$$P(a_1, \ldots a_n)$$

$$P : D^n \rightarrow \{T, F\}$$

- Arguments of predicates can be variables and constants
- Ground instances : Predicate all whose arguments are constants

N-ary Functions

$$f : D^n \rightarrow D$$

- Constants & Variables : Zero-order objects
- Predicates & Functions : First-order objects

Prime minister of India is older than the president of India

older(prime_minister(India), president(India))

Operators

$$\wedge \vee \sim \oplus \forall \rightarrow \exists$$

Universal Quantifier

Existential Quantifier

All men are mortal

Some men are rich

$$\forall x[man(x) \rightarrow mortal(x)]$$

$$\exists x[man(x) \wedge rich(x)]$$

Tautologies

$$\sim \forall x(p(x)) \rightarrow \exists x(\sim p(x))$$

$$\sim \exists x(p(x)) \rightarrow \forall x(\sim p(x))$$

- The second tautology reads as follows in English:
  - *Not a single man in this village is educated implies all men in this village are uneducated*
- Tautologies are important instruments of logic, but uninteresting statements!

Sets as foundations for semantics: notion of INTERPRETATION

- Logical expressions or formulae are “FORMS” (placeholders) for whom contents are created through interpretation.
- Example:

$$\exists F\left[\left\{F(a)=b\right\}\wedge\forall x\left\{P(x)\rightarrow\left(F(x)=g\left(x,F\left(h(x)\right)\right)\right)\right\}\right]$$

- This is a Second Order Predicate Calculus formula.
- Quantification on ‘F’ which is a function.

Example-1

- Interpretation #1

  $D=N$ (natural numbers)

  $a = 0$ and $b = 1$

  $x \in N$

  $P(x)$ stands for $x > 0$

  $g(m,n)$ stands for $(m \times n)$

  $h(x)$ stands for $(x - 1)$

- What does this interpretation mean?

Example-1

- Interpretation #1

  $D=N$ (natural numbers)

  $a = 0$ and $b = 1$

  $x \in N$

  $P(x)$ stands for $x > 0$

  $g(m,n)$ stands for $(m \times n)$

  $h(x)$ stands for $(x - 1)$

- Above interpretation defines **Factorial**

Example-2

- Interpretation-2

  D={strings)

  $a = b = \lambda$

  $P(x)$ stands for "x is a non empty string"

  $g(m, n)$ stands for "append head of m to n"

  $h(x)$ stands for *tail(x)*

- What does this interpretation mean?

Example-2

- Interpretation-2

  D={strings)

  $a = b = \lambda$

  $P(x)$ stands for "x is a non empty string"

  $g(m, n)$ stands for "append head of m to n"

  $h(x)$ stands for *tail(x)*

- Above interpretation defines "reversing a string"

Other examples

$$\exists P[\forall x \exists y P(x,y) \wedge \forall x \neg P(x,x) \wedge$$
$$\forall x \forall y \forall z[(P(x,y) \wedge P(y,z)) \Rightarrow P(x,z)]]$$

$$\forall x_1 x_2 x_3[\{P(x_1,x_1) \wedge P(x_2,x_2) \wedge P(x_3,x_3)\} \Rightarrow$$
$$\{P(x_1,x_2) \vee P(x_1,x_3) \vee P(x_2,x_3)\}]$$

True in all domains of cardinality <=3

Inferencing in model theory

Inferencing: Forward Chaining

- *man(x) → mortal(x)*
  - *Dropping the quantifier, implicitly Universal quantification assumed*
  - *man(shakespeare)*
- Goal mortal(shakespeare)
  - Found in one step
  - x = shakespeare, unification

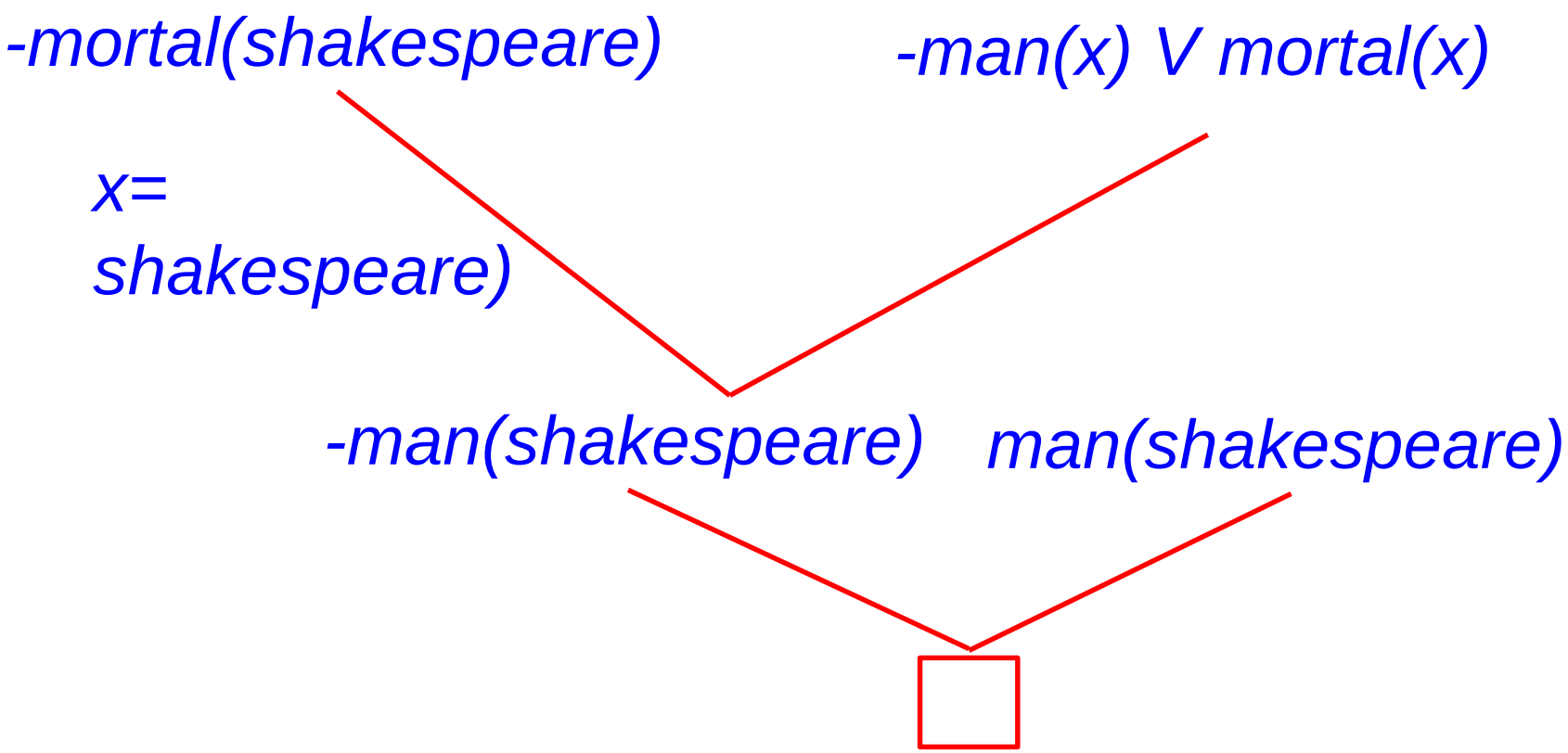
Backward Chaining

- $man(x) \rightarrow mortal(x)$
- Goal mortal(shakespeare)
  - x = shakespeare
  - Travel back over and hit the fact asserted
  - man(shakespeare)

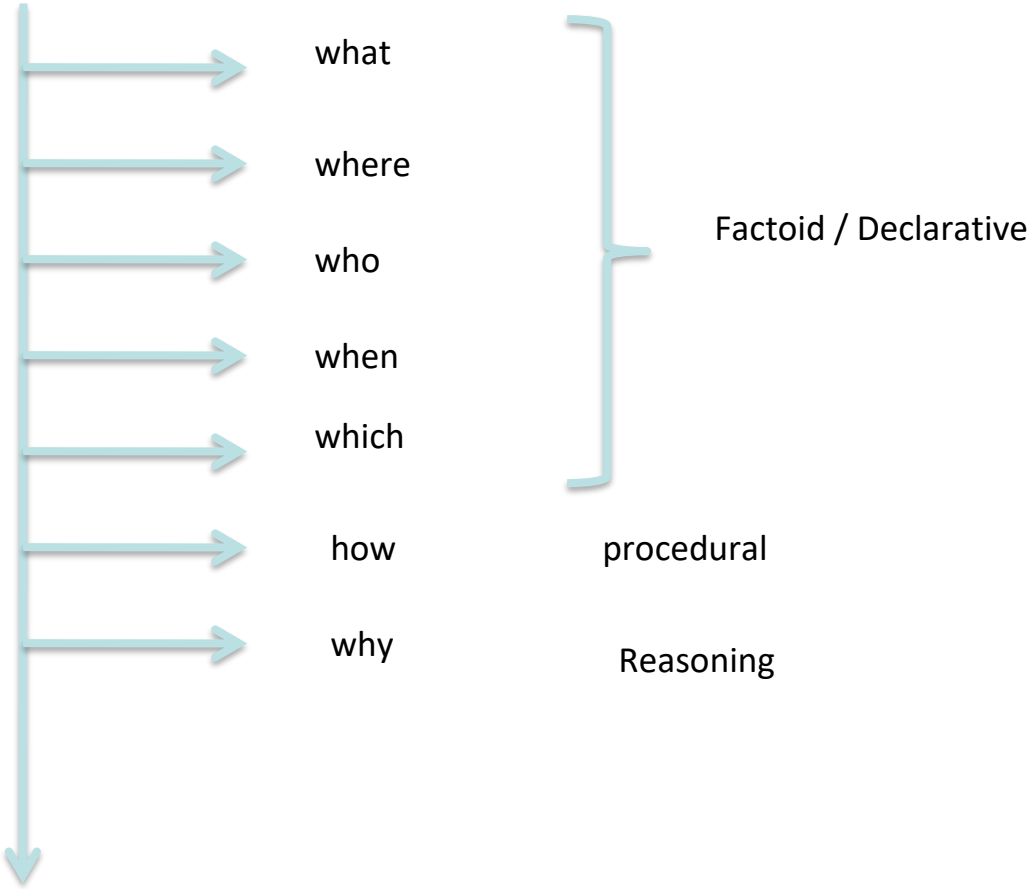
Resolution-Refutation

man(x) → *mortal(x)*, equivalent to

~man(x) V mortal(x)



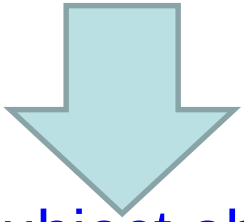
Wh-Questions and Knowledge



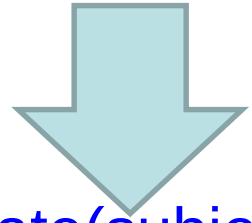
Fixing Predicates

- Natural Sentences

<Subject> <verb> <object>



Verb(subject,object)



predicate(subject)

Examples

- John is a boy
  - boy(John)
  - is_a(John,boy)

- John plays football
  - plays(John, football)
  - plays_football(John)

Representation of Complex Sentence

“In every city there is a thief who is beaten by every policeman in the city”

Model Theoretic Knowledge Representation of a Complex Sentence

"In every city there is a thief who is beaten by every policeman in the city"

$$\forall x[\text{city}(x) \rightarrow$$

$$\{\exists y((\text{thief}(y) \wedge \text{lives\_in}(y, x))$$

$$\wedge \forall z(\text{policeman}(z, x) \rightarrow \text{beaten\_by}(z, y)))\}]$$

Montague Semantics

Main source:
https://plato.stanford.edu/entries/montague-semantics/

What is it?

- A theory of natural language semantics and of its relation with syntax
- Originally developed by the logician Richard Montague (1930–1971)
- Most important features of the theory are its use of model theoretic semantics and principle of compositionality
  - Meaning of the whole is a function of the meanings of its parts and their mode of syntactic combination

Crux of the Framework

"*The basic aim of semantics is to characterize the notion of a true sentence (under a given interpretation) and of entailment (Montague 1970c, 373 fn)*"-

Richard Montague

"*There is in my opinion no important theoretical difference between natural languages and the artificial languages of logicians; indeed I consider it possible to comprehend the syntax and semantics of both kinds of languages with a single natural and mathematically precise theory. (Montague 1970c, 373)*"

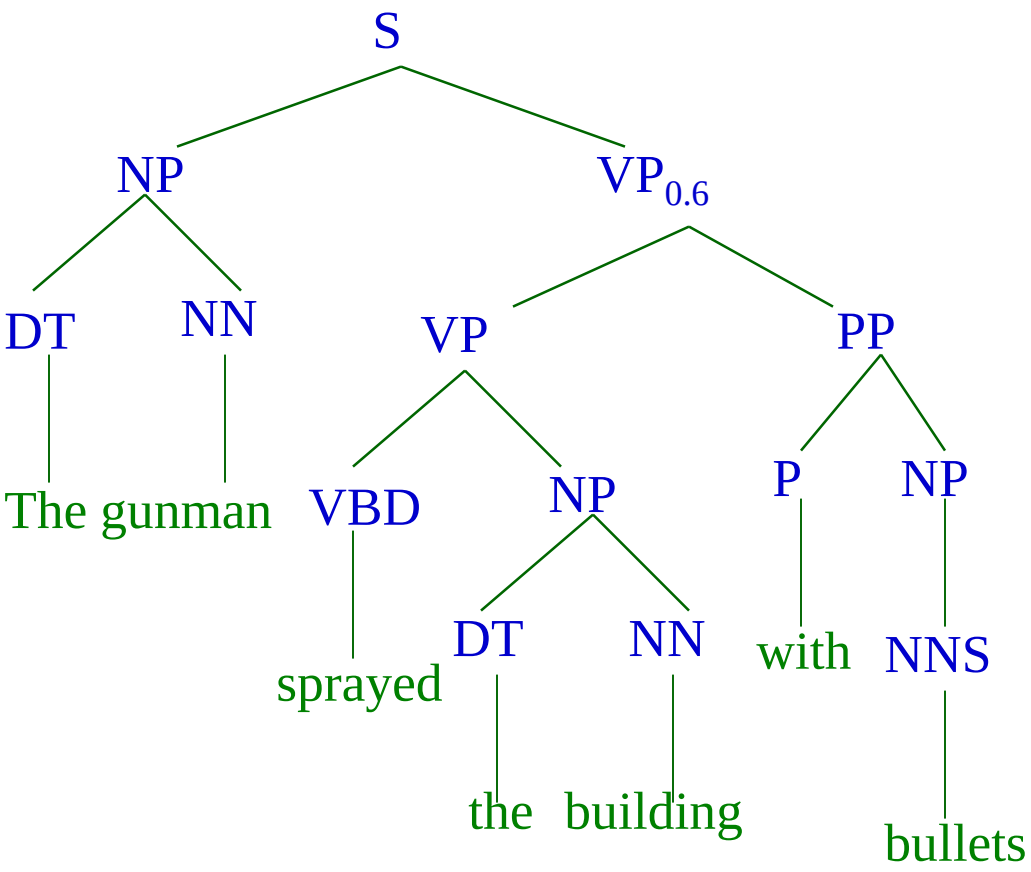
Richard Montague

Principle of Compositionality

- "The meaning of a compound expression is a function of the meanings of its parts and of the way they are syntactically combined. (Partee 1984, 281)"
- Very powerful idea!!
- Example
  - *S* → *NP VP*, therefore
  - meaning(S) → composition(meaning(NP), meaning(VP)

Example, syntax-semantics interaction

- The gunman sprayed the building with bullets.



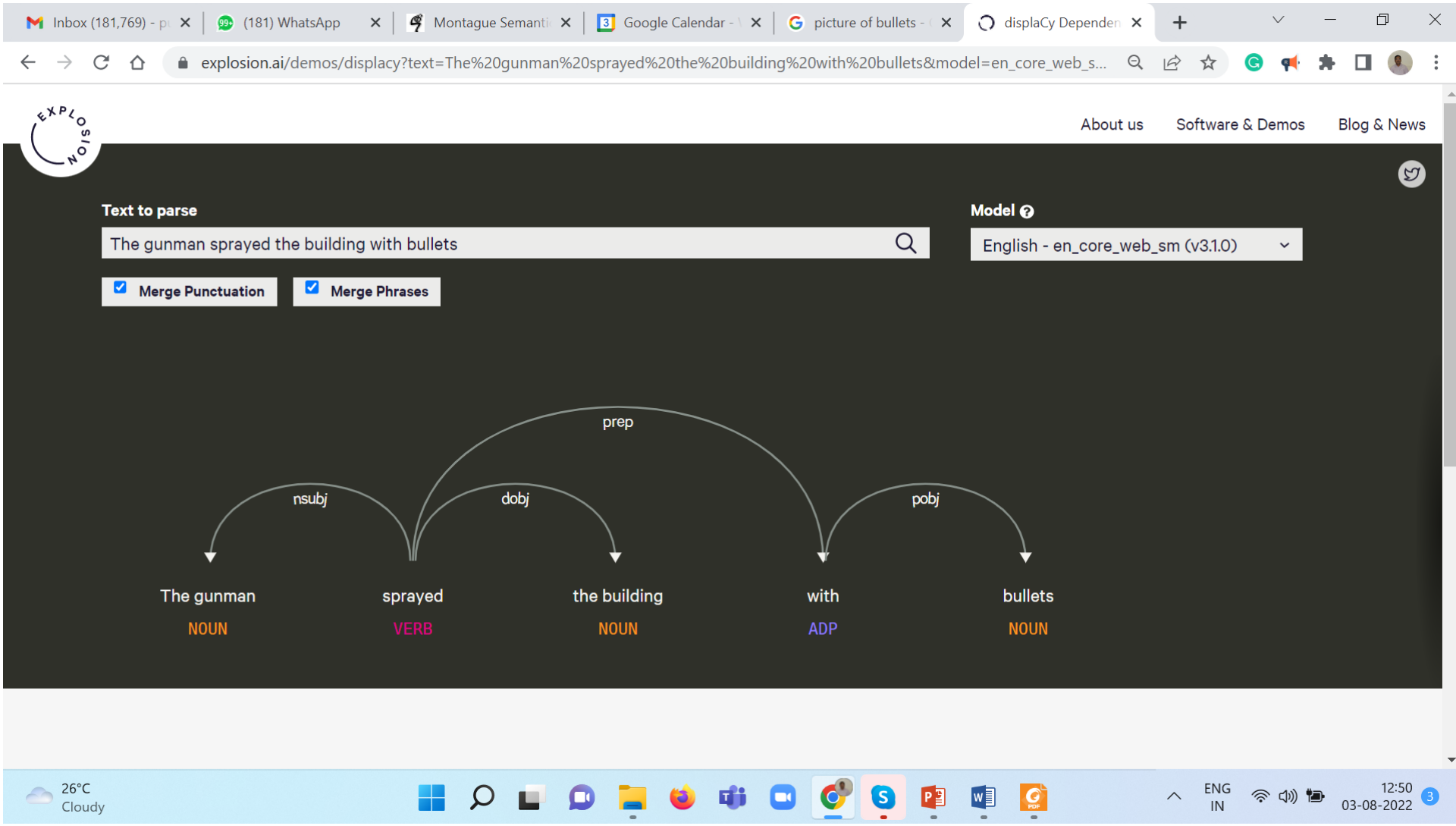
1. meaning(S)= meaning(NP)+meaning(VP)

2. meaning(NP)= meaning(DT)+meaning(NN) =meaning(‘the)+meaning(‘gunman’)= *a particular gunman, say, Daniel*

Representation of “Daniel”

- Position in a Lexicon: indexed (index: integer)
- Word vector of “Daniel”
- Properties of “Daniel”→ *human, male, skilled with gun, lives-in Utah (say), underwent-course-on-artillery,* and so on
- Will occupy a node in a humongous knowledge graph representing world knowledge
- Will occupy a place in an LLM like Bloom

Dependency Relations: "*the gunman…*"



Predicates

Shallow Representation

- *nsubj(spray, gunman)*
- *dobj(spray, building)*
- *prep(spray, bullet)*

Deeper Representation, embellished with speech acts (UNL style)

- *agt(spray:wordnet_id@past, gunman@def)*
- *obj(spray:wordnet_id@past, building@def)*
- *ins(spray:wordnet_id@past, bullet@pl)*

agt: agent of an action, *obj*: direct object of an action, *ins*: instrument of an action

@past: past tense, *@def*: definite entity, *@pl*: plural

Notion of “Reference”: linking language expression with Real World Entities and Relations

The building

The gunman

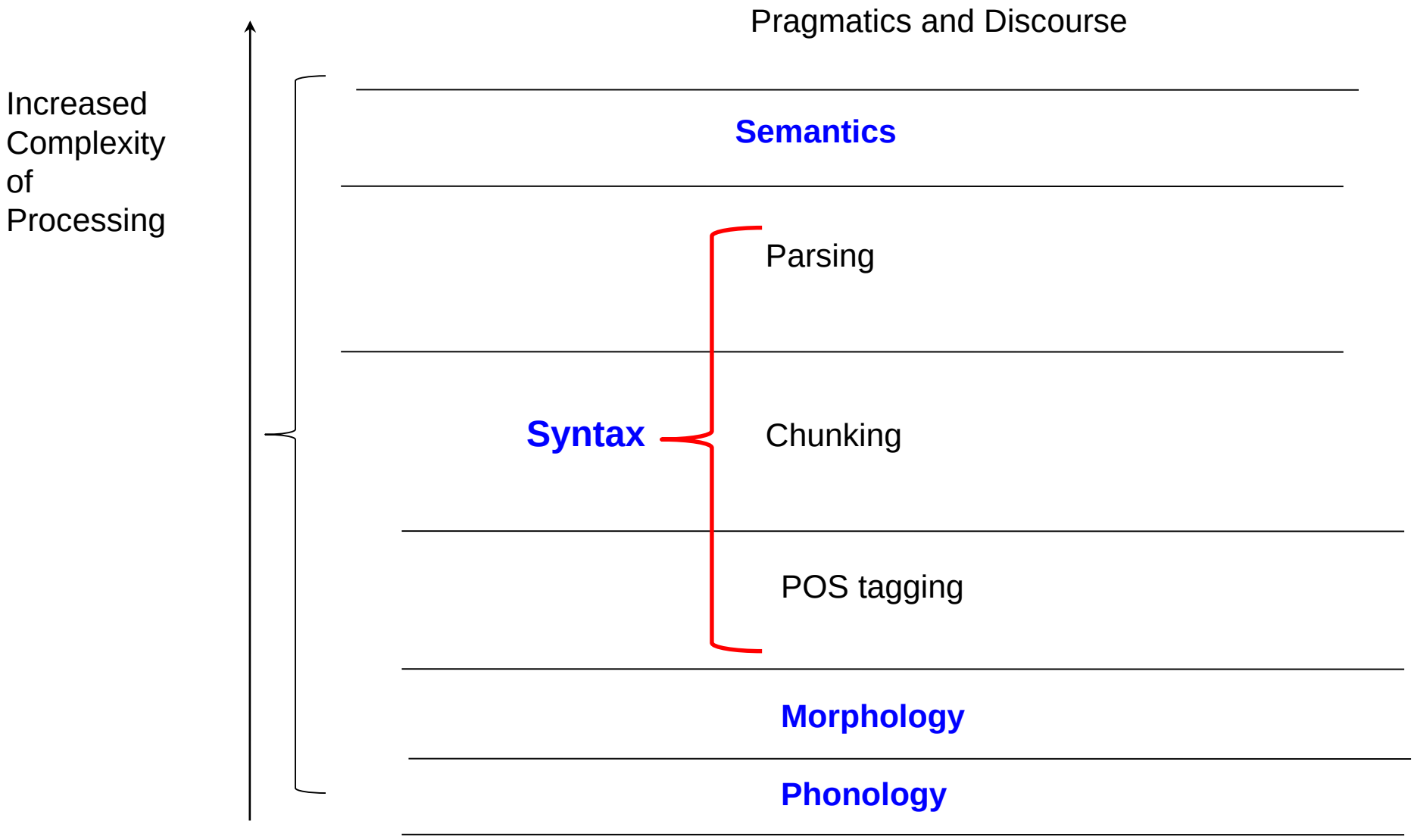
bullets

Thorn in the Flesh for Compositionality

- Metaphors (*where are you parked?)*
- Proverbs, (Hindi) *naach naa jaane aangan tedaa → a bad workman quarrels with the tools*
- Meaning cannot be inferred from lexical semantics and structure

Enter Pragmatics

NLP (and linguistics) Layers



Elements of Pragmatics (1/2)

- Deixis (literally, ‘pointing with words’: temporal- *now, then;* spatial- *here, there*; personal- *I, you, he, they*; definite-indefinite- *this, that, those)*

- Presupposition: (*untie the shoe* → presupposes *the shoe was tied before*)

Elements of Pragmatics (1/2)

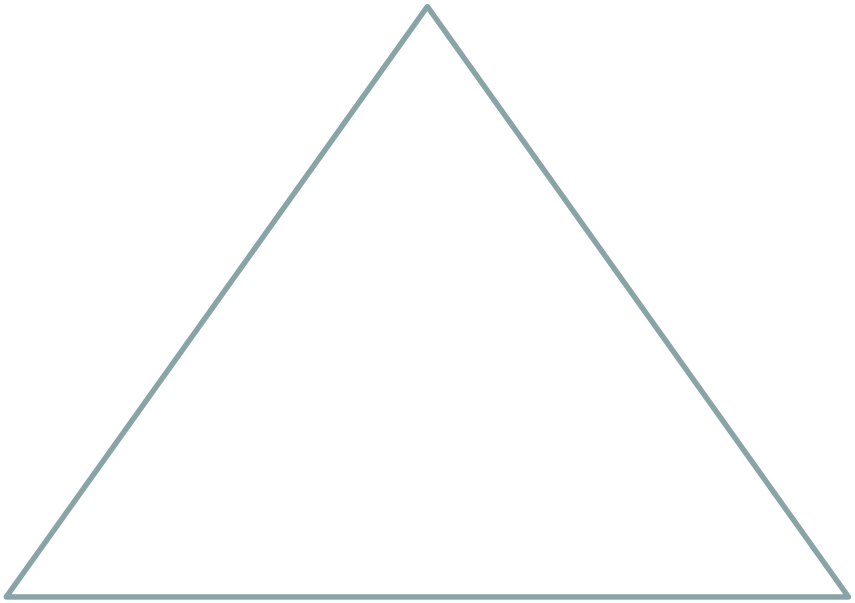
- Speech Acts: (*I pronounce you man and wife)*- **locutionary, illocutionary, and perlocutionary**
- Implicatures: (*A: shall we go for a walk? B: It is raining outside*)
- Politeness: (*close the door → please close the door → can you close the door → would you mind closing the door)*
- Information Structure: ordering of information (??*The table is under the flower pot*- odd; smaller object first mention) credit: Handke, Jürgen. 2013. Semantics and Pragmatics - Deixis. (1 November, 2014) http://www.youtube.com/watch?v=-LK-lc0wLf8

Crucial to Pragmatics

- Sentence vs. Utterance
- Semantics + Intent ➔ Pragmatics

The Trinity of Pragmatics

Linguistic Expression



Speaker **Hearer**

Communicative Aspects of language: nobody's baby? (Akmajian 2010) (1/2)

"Linguistics, focusing on structural properties of language, has tended to view communicative phenomena as outside its official domain. Likewise, it seems possible to pursue philosophical concerns about meaning, truth, and reference without investigating the details of communication. … cntd.

Communicative Aspects of language: nobody's baby? (Akmajian 2010) (2/2)

(from prev slide)…Traditional psychology of language has focused on the processing of sentences, but without much concern for the specifics of communicative phenomena. Finally, some sociologists and anthropologists concern themselves with conversations, but have bypassed (or assumed an answer to) the question of the nature of communication itself."

Syntax and semantics not enough

- “communicative process does not end with processing structural properties and decoding meaning.”
- Syntactic tree → uncovers the structure
- Model theoretic semantics → uncovers lexical semantics and compositional meaning

Problems beyond reach of plain syntax and semantics (1/2)

- Ambiguity: “Flying planes can be dangerous” → what is dangerous? Act of flying or the planes?- airport zoning meeting vs. Pilot Insurance Board
- Reference: “The weather here is good”: which weather? Where?
- Intention: “mei tumhe bataataa hu”: promise (I will tell you)? Threat (I will teach you a lesson)?

Problems beyond reach of plain syntax and semantics (2/2)

- Non-literality: Sarcasm, Metaphor: “I love being ignored”
- Indirection: “My car has a flat tire” to a car mechanic is not just stating a fact, but wants and action
- Non-communicative acts: “I pronounce you man and wife”: the act of legalizing the marriage is not exactly in the message which has a normative, formal standing

Conversational Presumptions

- Relevance: The speaker's remarks are relevant to the conversation.
- Sincerity: The speaker is being sincere.
- Truthfulness: The speaker is attempting to say something true.
- Quantity: The speaker contributes the appropriate amount of information.
- Quality: The speaker has adequate evidence for what she says.

Diexis

Credit: https://doi.org/10.1093/acrefore/9780199384655.013.213

Deictic Expressions

- Universal across languages
- "Used to individuate objects in the immediate context in which they are uttered, by pointing at them so as to direct attention to them."
- Results in the Speaker (Spr) and Addressee (Adr) attending to the same referential object.
  - *A: Oh, <u>there's that</u> guy again (pointing)*
  - *B:Oh yeah, <u>now</u> I see him (fixing gaze on the guy)*

Endophoric and Exophoric deixis

- Endophoric- refers to an object of discourse
- E.g., Anaphoric usage
  - “So you went to Boston, did you like it there?”

- Exophoric- Deictic (token) denotes an object in the extralinguistic context
  - “here, have a sip” (extending beverage to addressee)

Other Categorizations (Wikipedia)

- Personal: Grammatical person referred to, “do you know him?”
- Spatial: the place referred to, “do you enjoy living here?”
- Temporal: The time referred to, “he has gone now”
- Discourse: “This is a great story”; “that was a great account” (different from anaphora which refers to an ENTITY in the discourse, “I know the man, he lives in Delhi.”)
- Social: “thou, you” (En), “tu, tum, aap” (Hi), (honorifc) “aap ki shikshaa aallahabaad me hui” (“he” with respect)

Classifiers in Bengali: *ti, ta, te, to*

- Introduces definitiveness: shared understanding between the speaker and the addressee
  - ছেলেটি ভালো (Chēlēṭi bhālō): the boy is good
  - দুটো আম (duṭō ām): two mangoes
  - চারটে বেড়াল (Cāraṭē bēṛāla): four cats
  - An aside: East Asian languages, including Chinese, Korean, Japanese, and Vietnamese have classifiers. Classifiers are absent or marginal in European languages. In English, the work “piece”: *three pieces of paper*

Speech Act

Definition

- **“speech act** is something expressed by an individual that not only presents information but performs an action as well” (Wikipedia)

- Purpose of language is not only to pass on information, but also to achieve an end

- Speech act is Speech+ Act
  - “I hereby resign from this job”

Kinds of Speech Act

- Locutionary
- Illocutionary
- Perlocutionary
- Performative Speech acts

Locutionary Speech Act

- The meaning that is on the surface of the utterance
  - *It is raining* → Stating the fact that it is raining

Sanskrit Linguistics

- Vachyartha, Lakshyartha, Vyangaartha

- **“Gangaa”:**
  - *vaachyaartha:* The river Gangaa (due to abhidhaa)
  - *lakshyaartha: gangaayaaM ghoshaH:* the house on river gangaa, meaning “on the bank of” (due to lakshanaa)
  - *Vyangaartha:* the house will have nice view, breeze etc. (unsaid) (due to vyanjana)

Illocutionary Speech Acts

- "By saying something, we do something"- J. L. Austin 1962 (The classic book- "How to do things with words", Harvard University Press)

- Example:
  - A to B on a dining table, pointing to a jug: *Is that water,* meaning a request: *pl pass me the water*

Perlocutionary Speech Acts

- Perlocutionary acts always have a 'perlocutionary effect' which is the effect a speech act has on a listener

- Example:
  - A to B: *I am hungry*
  - (B goes to the fridge) *here have this sandwitch*

Performative Speech Acts

- Action that the sentence describes is performed by the utterance of the sentence itself
- Has self-reference!
- Examples
  - *I nominate you the chairman* (as opposed to *you are the chairman of the)*
  - *I pronounce you man and wife* (as opposed to *you now become man and wife)*
  - *I promise to pay you back* (as opposed to *I will pay you back*)

Subtle Differences between illocutionary, perlocutionary and performative (1/2)

- Illocutionary: express the intent (speaker centric)
- Perlocutionary: effect on the addressee (listener centric)
- Performative: self reference

Difference cntd.

- Example: *I promise you to pay back*
- Illocutionary: Intent to stick to the utterance
- Perlocutionary: The addressee accepts/rejects
- Performative: the utterance itself is the promise!

Implicatures

Examples all around

- Sign on a room in Amsterdam Airport:
  - BABY CHANGING ROOM (*what is changed in the room!)*
- A to B: *shall we go for a walk?*
- B*: it is raining outside* (implies ‘no’)

Implicatures and Abductive Reasoning

- Both are defeasible (can be ‘cancelled’)
- Digression
  - Deductive reasoning: *all men are mortal, Shakespeare is a man → Shakespeare is mortal* (indefeasible, provided axioms are indeed true)
  - Inductive Reasoning: *crows in Delhi are black, crows in Mumbai are black, …→ all crows are black* (defeasible)
  - Abductive Reasoning: *if rain no cricket, no cricket → rain* (defeasible)

Implicatures are defeasible

- A: *shall we go for a walk?*
- B: *it is raining* (so no?)
- B: *I will take my rain coat* (yes☺)

Another categorization of speech act (1/2) *(J & M, 2006)*

- **Assertives:** committing the speaker to something's being the case (*suggesting*, *putting forward*, *swearing*, *boasting*, *concluding*).

- **Directives:** attempts by the speaker to get the addressee to do something (*asking*, *ordering*, *requesting*, *inviting*, *advising*, *begging*).

Another categorization of speech act (2/2)

- **Commissives:** committing the speaker to some future course of action (*promising, planning, vowing, betting, opposing*).
- **Expressives:** expressing the psychological state of the speaker about a state of affairs *thanking*, *apologizing*, *welcoming*, *deploring*.
- **Declarations:** bringing about a different state of the world via the utterance (including many of the performative examples above; *I resign*, *You're fired*.)

Summary of the course

- 1. Introduction
- 2. POS Tagging
- 3. Parsing
  - a. Constituency
  - B. dependency
- 4. Lexical Semantics
- 5. Word Sense Disambiguation
- 6. Feedforward N/W and Backpropagation
- 7. Softmax and Cross Entropy
- 8. Word Embeddings
- 9. Alignment
- 10. Machine Translation-Phrase Based
- 11. MT Evaluation
- 12. Sentential Semantics-Montague
- 13. Pragamatics

Thank you

All the best