Semantic Theory
Semantics Construction (ctd.)

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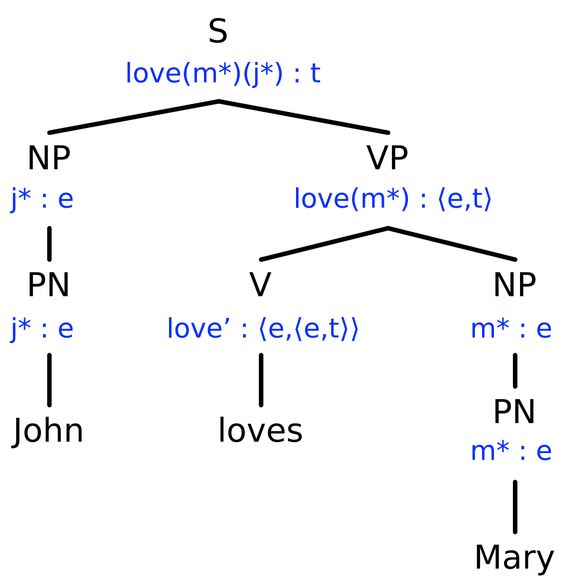
Last Lecture: Semantics Construction

- Elementary semantics construction:
  - the principle of compositionality
  - compositional semantics construction using type theory
- Quantified noun phrases
- Lambda-abstraction and β-reduction

The Principle of Compositionality

- The meaning of a complex expression is uniquely determined by the meanings of its sub-expressions and the syntactic rules by which they are combined.
- (The principle is also called “Frege’s principle”)

An Example



Noun phrases and compositionality

John works ⇒ work'(j*)

Somebody works ⇒ ∃x(work'(x))

Every student works ⇒ ∀x(student'(x) → work'(x))

No student works ⇒ ¬∃x(student'(x) ∧ work'(x))

John and Mary work ⇒ work'(j*) ∧ work(m*)

- What's the semantic representation of a noun phrase?

λ-Abstraction

- Syntax:
  - If $\alpha \in WE_\tau$ and $v \in VAR_\sigma$, then $\lambda v\alpha \in WE_{(\sigma,\tau)}$.
- Semantics:
  - $[\![\lambda v\alpha]\!]^{M,g}$ is that function $f : D_\sigma \rightarrow D_\tau$ such that for all $a \in D_\sigma$, $f(a) = [\![\alpha]\!]^{M,g[v/a]}$ (for $\alpha \in WE_\tau$, $v \in VAR_\sigma$)
  - $[\![(\lambda v\alpha)(\beta)]\!]^{M,g} = [\![\alpha]\!]^{M,g[v / [\![\beta]\!]^{M,g}]}$

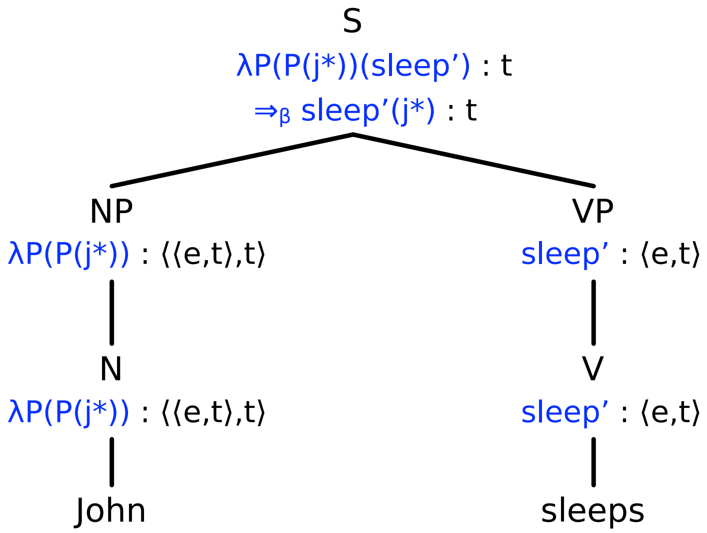
Conversion rules in the λ-calculus

- β-conversion:
  $\lambda v\alpha(\beta) \Leftrightarrow [\beta/v]\alpha$ if all free variables in β are free for v in α.
- α-conversion:
  $\lambda v\alpha \Leftrightarrow \lambda v'[v'/v]\alpha$ if v' is free for v in α.
- η-conversion:
  $\lambda v(\alpha(v)) \Leftrightarrow \alpha$
- Let v, v' be variables of the same type, α any well-formed expression. v is free for v' in α iff no free occurrence of v' in α is in the scope of a quantifier or a λ-operator that binds v.

Noun Phrases

John	$\Rightarrow \lambda G(G(j^*))$
Somebody	$\Rightarrow \lambda G\ \exists x G(x)$
A student	$\Rightarrow \lambda G\ \exists x(student(x) \wedge G(x))$
No student	$\Rightarrow \lambda G\ \neg\exists x(student(x) \wedge G(x))$
John and Mary	$\Rightarrow \lambda G(G(j^*) \wedge G(m^*))$

“John sleeps”



Determiners

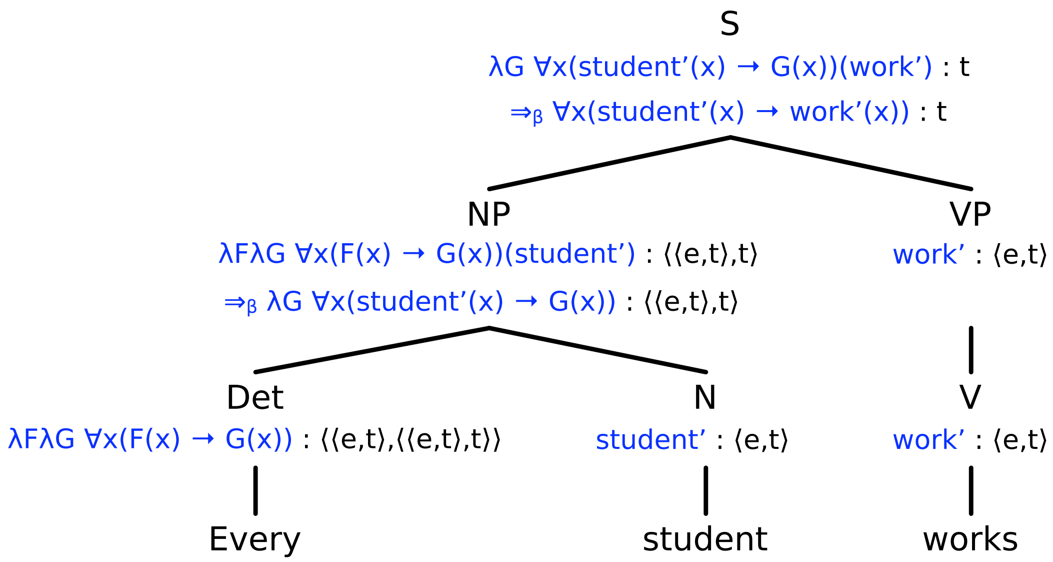
a, some ⇒ $\lambda F \lambda G\ \exists x(F(x) \wedge G(x))$

every ⇒ $\lambda F \lambda G\ \forall x(F(x) \rightarrow G(x))$

no ⇒ $\lambda F \lambda G\ \neg\exists x(F(x) \wedge G(x))$

most ⇒ most’ (a constant)

“Every student works.”



Today

- Semantics construction for further constructions:
  - adjectives
  - transitive verbs
- Intensional Logic (sketch)

Back to Adjectives

(1) *John is a blond criminal*

- criminal'(j*) ∧ blond'(j*)

(2) *John is a famous criminal*

- criminal'(j*) ∧ famous'(j*) ?

(3) *John is an alleged criminal*

- criminal'(j*) ∧ alleged'(j*) ???

(4) *John is a student*

- (1) + (4) entail that John is a blond student,
- but (2) + (4) do not entail that John is a good student.
- (3) does not even entail that John is a criminal.

Back to Adjectives

(1) *John is a blond criminal*

- blond'(criminal')(j*)

(2) *John is a famous criminal*

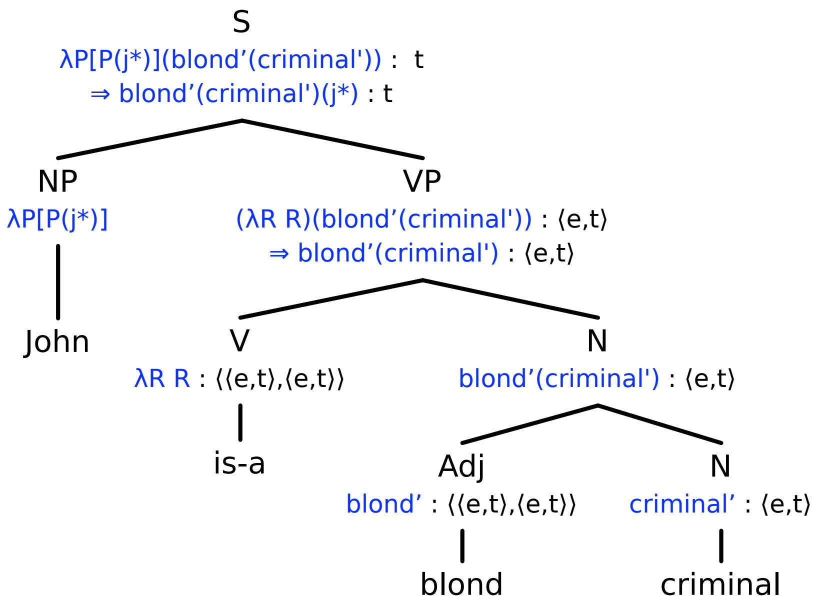
- famous'(criminal')(j*)

(3) *John is an alleged criminal*

- alleged'(criminal')(j*)

- Now the unwanted inferences disappear …
  (at the price of a less explicit semantic representation)

“John is a blond criminal.”



Adjective Classes

- Adjectives can be classified with respect to the way they combine the adjective and noun meanings:
  - intersective adjectives (blond, carnivorous, ...): ⟦ blond N ⟧ = ⟦ blond ⟧ ∩ ⟦ N ⟧
  - subsective adjectives (skillful, typical, ...): ⟦ skillful N ⟧ ⊆ ⟦ N ⟧
  - privative adjectives (past, fake, ...): ⟦ past N ⟧ ∩ ⟦ N ⟧ = ∅
  - there are also other non-subsective adjectives that are not privative (alleged, ...)

Adjectives

- We want:
  - compositional semantics construction
  - explicit and meaningful semantic representations
- We don't have this yet for (intersective) adjectives.
- We can get this in two different ways
  - use meaning postulates
  - use more explicit lambda terms

Meaning Postulates

- Characterise the meaning of a predicate that stands for a word (e.g., "blond") by using logical axioms.
- Meaning postulate for intersective adjectives ("blond"):
  - $\forall P \forall x(\text{blond}'(P)(x) \rightarrow P(x))$
- These axioms would be part of our background knowledge.
- For example, we could infer "criminal(john)" from "blond(criminal)(john)" and this axiom.

More Explicit Lambda Terms

- For intersective adjectives, we can also do it by assigning the word a more elaborate lambda term:
  - blond‘ = $\lambda P \lambda x(P(x) \wedge \text{blond}^*(x))$
  - where “blond*” is a constant of type $\langle e,t \rangle$ which should denote the set of blond individuals in the universe.
- This will beta-reduce to the formula we want.

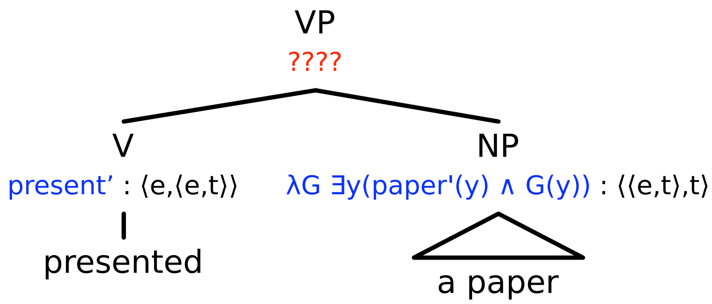
Transitive Verbs

- A composition problem:

every student ⇒ $\lambda F\ \forall x(\text{student}'(x) \rightarrow F(x)) : \langle\langle e,t\rangle,t\rangle$

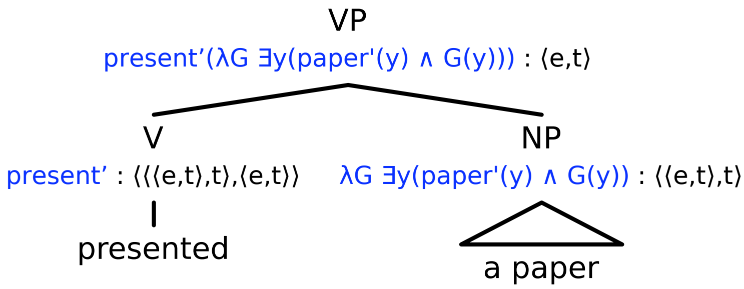
a paper ⇒ $\lambda G\ \exists y(\text{paper}'(y) \wedge G(y)) : \langle\langle e,t\rangle,t\rangle$

presented ⇒ $\text{present}' : \langle e,\langle e,t\rangle\rangle$



The solution: Type-Raising

- Solution: raise the type of the first-order relation:
  - present’: $\langle\langle\langle e,t\rangle,t\rangle,\langle e,t\rangle\rangle$



Transitive Verbs

- But now our semantic representation no longer beta-reduces to a FOL formula.
  - $\forall x(\text{student}'(x) \rightarrow \text{present}'(\lambda G \exists y\ \text{paper}'(y) \wedge G(y))(x))$
- Same problem as with intersective adjectives, same solution.
- Represent transitive verbs like “present” as follows:
  - $\lambda Q \lambda x(Q(\lambda y(\text{present}^*(y)(x))))$: $\langle\langle\langle e,t\rangle,t\rangle,\langle e,t\rangle\rangle$,
  - where present*: $\langle e,\langle e,t\rangle\rangle$

"… presented a paper"

- *a paper* ⇒ λG∃z(paper'(z) ∧ G(z))
- *presented* ⇒ λQλx[Q(λy[present*(y)(x)])]
- *presented a paper*
  - ⇒ λQλx[Q(λy[present*(y)(x)])](λG∃z(paper'(z) ∧ G(z)))
  - ⇒ λx[λG∃z(paper'(z) ∧ G(z))(λy[present*(y)(x)])]
  - ⇒ λx[∃z(paper'(z) ∧ λy[present*(y)(x)](z)]
  - ⇒ λx[∃z(paper'(z) ∧ present*(z)(x)]

Substitutability

- From the denotational version of the Principle of Compositionality, a substitution principle follows:
  - If A is sub-expression in a sentence S, and A and B have identical denotations, then A can be replaced by B in S without affecting the truth value of S.

(1) *George W. Bush is married to Laura Bush.*

(2) *George W. Bush is the American president*

(3) *The American president is married to Laura Bush.*

Substitutability?

(1) *In 1977, George W. Bush married Laura Bush.*

(2) *George W. Bush is the American president*

(3) *In 1977, the American president married Laura Bush.*

Substitutability?

(1) *By constitution, the American president is the Supreme Commander of the Armed Forces.*

(2) *George W. Bush is the American president.*

(3) By constitution, George W. Bush is the Supreme Commander of the Armed Forces.

Substitutability?

(1) *Nine necessarily exceeds seven*.

(2) *Nine is the number of planets*

(3) *The number of planets necessarily exceeds seven*.

Extensions vs. Intensions

- Two concepts have the same extension if they have the same interpretations:
  - ”semantics lecture is taking place” and ”2 + 2 = 4” are both true right now
  - ”George W. Bush” and “the US president” refer to the same individual
- However, extensionally equal concepts may still have different ”senses:” General truths vs. statements that may become false; can believe in one but not the other...
- These senses are also called intensions.

Intensions

- We need intensions to explain (non-) substitutability in many contexts:
  - propositional attitudes (believe, know, ...)
  - indirect speech (say, claim, ...)
  - tensed sentences (past, future, ...)
  - temporal adverbs (sometimes, always, tomorrow, ...) and connectives (before, during, ...)
  - modal adverbs (necessarily, perhaps, ...),
  - modal verbs (can, may, must, ...),
  - counterfactual conditionals

Modelling Intensions

- In order to capture the meaning of a NL expression completely, we must extend the logic to talk about intensions.
- Standard technique:
  - Introduce the concept of a ”possible world”;
  - define the extension of a term in each possible world;
  - the intension is the mapping of possible worlds to extensions.

Intensional Logics

- Model logic: mechanisms for talking about possible worlds
  - □p "it is necessarily the case that p"
    (universal quantification over possible worlds)
  - ◇p "is is possibly the case that p"
    (existential quantification over possible worlds)

Intensional Logics

- Temporal logic: mechanisms for talking about time
  - **F**p "it will at some stage be the case that p"
  - **G**p "it is always going to be the case that p"
  - **P**p "it was at some stage the case that p"
  - **H**p "it always has been the case that p"

Intensional Logics

- Montagues Intensional Logic (IL)
  - model and temporal operators
  - plus abstraction over possible worls: ^p denotes the function mapping possible worlds w to the denotation of p at w.

Substitutability, revisited

(1) *Nine necessarily exceeds seven*.
$\Box(9 > 7)$

(2) *Nine is the number of planets*
9 = the number of planets

(3) *The number of planets necessarily exceeds seven*.
$\Box$(the number of planets > 9)

Substitutability, revisited

(1) *John said that Mary kissed Bill.*
say‘(j*, ^kiss’(m*, b*))

(2) *Bill is the smartest boy in class*
x = the smartest boy in class

(3) *John said that Mary kissed the smartest boy in class.*
say‘(j*, ^kiss’(m*, the smartest boy in class))