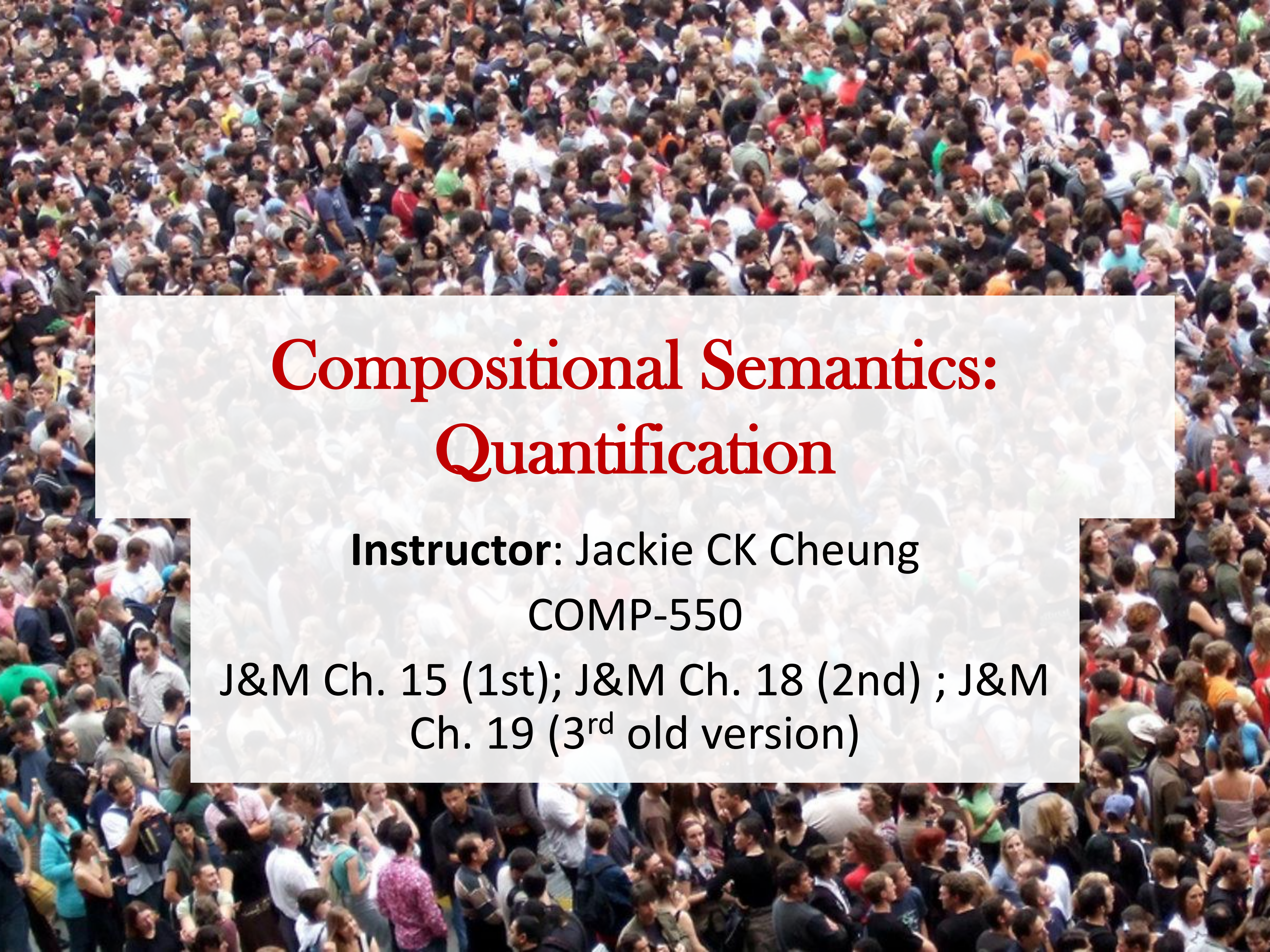

Compositional Semantics: Quantification

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COMP-550

J&M Ch. 15 (1st); J&M Ch. 18 (2nd) ; J&M Ch. 19 (3rd old version)

Outline

Syntax-driven semantic composition

- Nouns
- Intransitive and transitive verbs

Quantifiers

- Universal and existential quantifiers
- Definite descriptions

Power of Lambda Calculus

They allow us to store partial computations of the MR, as we are composing the meaning of the sentence constituent by constituent.

Whiskers disdained catnip.

disdained $\lambda x.\lambda y.disdained(y,x)$

disdained catnip $\left(\lambda x.\lambda y.disdained(y,x)\right)\ catnip$

$= \lambda y.disdained(y,catnip)$

Whiskers disdained catnip

$\left(\lambda y.disdained(y,catnip)\right) Whiskers$

$= disdained(Whiskers,catnip)$

Syntax-Driven Semantic Composition

Augment CFG trees with lambda expressions

- Syntactic composition = function application

Semantic attachments:

$A \rightarrow \alpha_1 \; \ldots \alpha_n$ $\{f(\alpha_j.sem, \ldots, \alpha_k.sem)\}$

syntactic composition semantic attachment

Proper Nouns

Proper nouns are FOL constants

$$PN \rightarrow COMP550 \qquad \{COMP550\}$$

Actually, we will **type-raise** proper nouns

$$PN \rightarrow COMP550 \qquad \{\lambda x.\, x(COMP550)\}$$

- It is now a function rather than an argument.
- We will see why we do this.

NP rule:

$$NP \rightarrow PN \qquad \{PN.sem\}$$

Common Nouns

Common nouns are predicates inside a lambda expression of type $\langle e, t \rangle$

- Takes an entity, tells you whether the entity is a member of that class

$$N \rightarrow student \qquad \{\lambda x. Student(x)\}$$

Intransitive Verbs

We introduce an *event variable* e, and assert that there exists a certain event associated with this verb, with arguments.

$$V \rightarrow rules \qquad \{\lambda x. \exists e. Rules(e) \land Ruler(e, x)\}$$

Then, composition is

$$S \rightarrow NP\ VP \qquad \{NP.sem(VP.sem)\}$$

Let's derive the representation of the sentence "*COMP-550 rules*"

Neo-Davidsonian Event Semantics

Notice that we have changed how we represent events

Method 1: multi-place predicate

$Rules(x)$

Method 2: Neo-Davidsonian version with event variable

$\exists e. Rules(e) \land Ruler(e, x)$

Reifying the event variable makes things more flexible

- Optional elements such as location and time, passives
- Add information to the event variable about tense, modality

Transitive Verbs

Transitive verbs

$V \rightarrow enjoys$

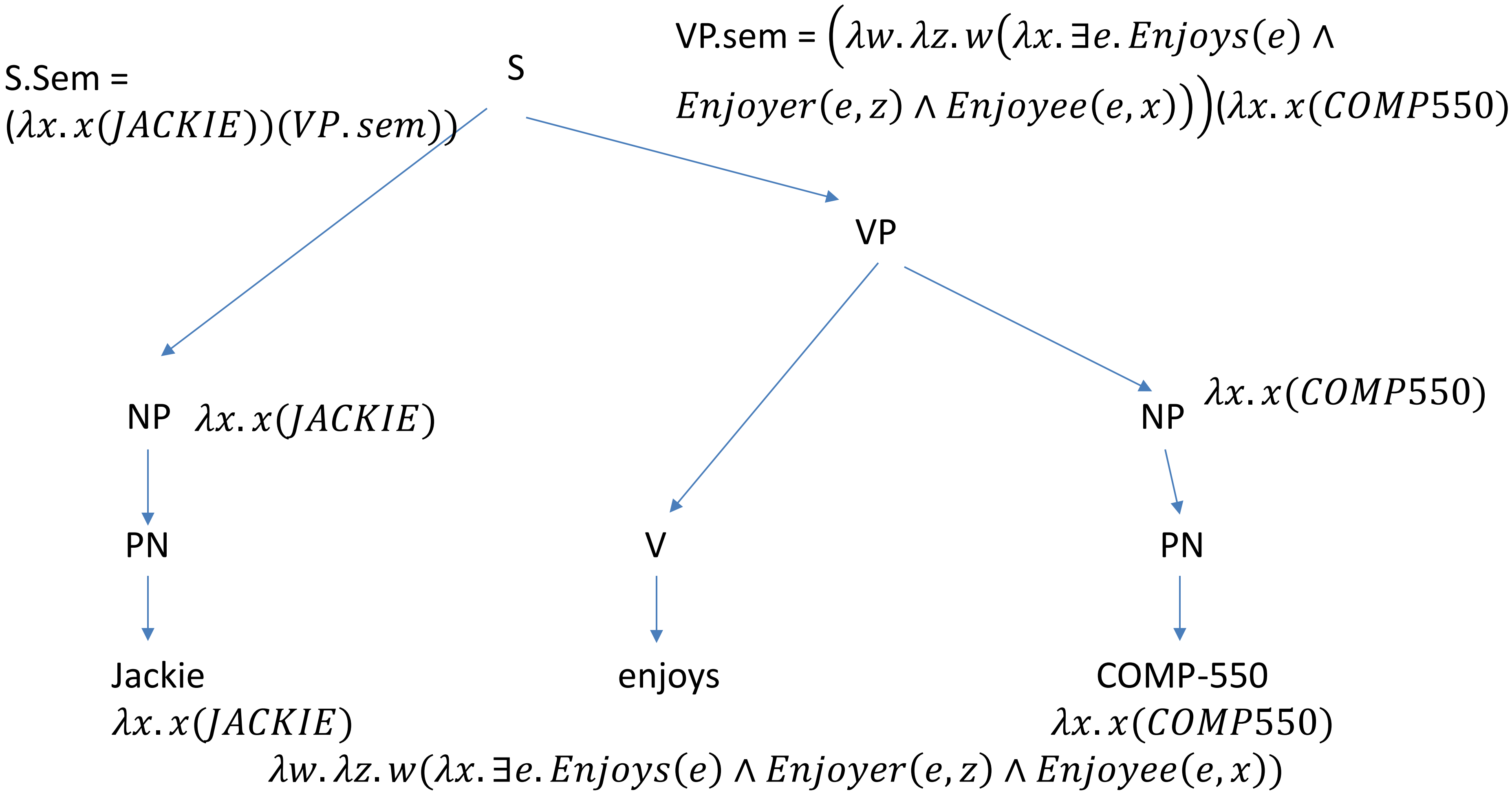
$\{\lambda w. \lambda z. w(\lambda x. \exists e. Enjoys(e) \land Enjoyer(e, z) \land Enjoyee(e, x))\}$

$VP \rightarrow V\ NP \qquad \{V.sem(NP.sem)\}$

$S \rightarrow NP\ VP \qquad \{NP.sem(VP.sem)\}$

Exercise: verify that this works with the sentence "*Jackie enjoys COMP-550*"

Jackie Enjoys COMP-550



Simplification

VP.sem = $\left(\lambda w.\lambda z.w\left(\lambda x.\exists e.Enjoys(e) \wedge Enjoyer(e,z) \wedge Enjoyee(e,x)\right)\right)(\lambda x.x(COMP550))$

$$\left(\lambda z.(\lambda y.y(COMP550))\left(\lambda x.\exists e.Enjoys(e) \wedge Enjoyer(e,z) \wedge Enjoyee(e,x)\right)\right)$$

$$\left(\lambda z.\left(\lambda x.\exists e.Enjoys(e) \wedge Enjoyer(e,z) \wedge Enjoyee(e,x)\right)(COMP550)\right)$$
$$\left(\lambda z.\left(\exists e.Enjoys(e) \wedge Enjoyer(e,z) \wedge Enjoyee(e,COMP550)\right)\right)$$

S.Sem = $(\lambda x.x(JACKIE))(VP.sem)$

=$(\lambda x.x(JACKIE))\left(\lambda z.\left(\exists e.Enjoys(e) \wedge Enjoyer(e,z) \wedge Enjoyee(e,COMP550)\right)\right)$

= $\left(\lambda z.\left(\exists e.Enjoys(e) \wedge Enjoyer(e,z) \wedge Enjoyee(e,COMP550)\right)\right)JACKIE$

= $\left(\exists e.Enjoys(e) \wedge Enjoyer(e,JACKIE) \wedge Enjoyee(e,COMP550)\right)$

Quantifiers

Universal quantifiers

- *all, every*

All students like COMP-550.

$\forall x. Student(x) \rightarrow Like(x, \mathrm{COMP{-}550})$

Existential quantifiers

- *a, an, some*

Some/A student likes COMP-550.

$\exists x. Student(x) \wedge Like(x, \mathrm{COMP{-}550})$

Why $\rightarrow$ for the universal quantifier, but $\wedge$ for the existential one?

Russell (1905)'s Definite Descriptions

How to express "*the student*" in FOL?

e.g., *The student took COMP-550.*

Need to enforce three properties:

1. There is an entity who is the student.
2. There is at most one thing being referred to who is a student.
3. The student participates in some predicate, here, "*took COMP-550*".

The King of France is Bald

Property 1 is important. Consider "*The King of France is bald.*"

Solution 1:

- Define a new constant for KING-OF-FRANCE, much like for proper nouns.

FOL MR becomes $Bald(\mathrm{KING{-}OF{-}FRANCE})$

What is the problem with this solution?

Definite Articles

The student took COMP-550:

1. There is an entity who is the student.
2. There is at most one thing being referred to who is a student.
3. The student participates in some predicate.

What is the range of this existential quantifier?

$$\exists x. Student(x) \land \forall y. (Student(y) \rightarrow y = x)$$
$$\land\ took(x, \text{COMP}-550)$$

For simplicity, for now, assume took is a predicate, rather than use event variables.

Incorporating into Syntax

Now, let's incorporate this to see how lambda calculus can deal with this compositionally.

Semantic attachment for lexical rule for *every*:

$Det \rightarrow every \qquad \{\lambda P.\lambda Q.\forall x.P(x) \rightarrow Q(x)\}$

What do P and Q represent?

Every Student Likes COMP-550

$Det \rightarrow every \qquad \{\lambda P.\lambda Q.\forall x.P(x) \rightarrow Q(x)\}$

$NP \rightarrow Det\ N \qquad \{Det.sem(N.sem)\}$

Let's do the derivation of *Every student likes COMP-550*.

Recall:

$VP \rightarrow V\ NP \qquad \{V.sem(NP.sem)\}$

$S \rightarrow NP\ VP \qquad \{NP.sem(VP.sem)\}$

$V \rightarrow likes$

$$\{\lambda w.\lambda z.w(\lambda x.\exists e.Likes(e) \land Liker(e,z) \land Likee(e,x))\}$$

Using explicit event variables again.

Every Student

$Det \rightarrow every$ $\{\lambda P.\lambda Q.\forall x.P(x) \rightarrow Q(x)\}$

$NP \rightarrow Det\ N$ $\{Det.sem(N.sem)\}$

Let’s do the derivation of *Every student*

NP.sem = $(\lambda P.\lambda Q.\forall x.P(x) \rightarrow Q(x))(\lambda x.Student(x))$

= $\lambda Q.\forall x.(\lambda y.Student(y))(x) \rightarrow Q(x)$
= $\lambda Q.\forall x.Student(x) \rightarrow Q(x)$

Questions and Exercise

What are the lexical rules with semantic attachments for *a*? For *the*?

Come up with the derivation of *COMP-550 likes every student.*

Adjectives

Can we figure out the pattern for adjectives?

student	$\lambda x. Student(x)$
smart student	$\lambda x. Smart(x) \wedge Student(x)$
smart	?

Also need an augmented rule for N -> A N

Scope Ambiguity: Multiple Quantifiers

What are the possible readings for the following?

Every student took a course.

This is known as **scopal ambiguity**.

Scope Ambiguity

Every student took a course.

every > a

$\forall x. Student(x)$
$\rightarrow (\exists y. Course(y) \wedge \exists e. took(e) \wedge taker(e, x) \wedge takee(e, y))$

a > every

$\exists y. Course(y)$
$\wedge \left(\forall x. Student(x) \rightarrow \exists e. took(e) \wedge taker(e, x) \wedge takee(e, y)\right)$

Would like a way to derive **both** of these readings from the syntax. What would we get with our current method?

Underspecification

Solution: Derive a representation that allows for both readings

Underspecified representation – A meaning representation that can embody all *possible* readings without explicitly enumerating all of them.

Other cases where this is useful:

- We are genuinely missing some information (e.g., the tense information), so we choose not to include it in the meaning representation.

Cooper Storage (1983)

Associate a **store** with each FOL expression that allows both readings to be recovered.

Every student took a course.

$$\exists e.\, took(e) \land taker(e, s_1) \land takee(e, s_2)$$

$$(\lambda Q.\, \forall x.\, Student(x) \rightarrow Q(x), 1),$$

$$(\lambda Q.\, \exists y.\, Course(y) \land Q(y), 2)$$

Recovering the Reading

Once we know which reading we want (e.g., by looking at the context), recover the store:

1. Select order to incorporate quantifiers
2. For each quantifier:
   - Introduce lambda abstraction over the appropriate index variable
   - Do beta-reduction

Example: 1, then 2

Every student took a course.

$\exists e.\, took(e) \wedge taker(e, s_1) \wedge takee(e, s_2)$

$(\lambda Q.\, \forall x.\, Student(x) \rightarrow Q(x), 1),$

$(\lambda Q.\, \exists y.\, Course(y) \wedge Q(y), 2)$

1 first:

$\big(\lambda Q.\, \forall x.\, Student(x) \rightarrow Q(x)\big)$

$\big(\lambda s_1.\, \exists e.\, took(e) \wedge taker(e, s_1) \wedge takee(e, s_2)\big)$

$= \forall x.\, Student(x) \rightarrow \exists e.\, took(e) \wedge taker(e, x) \wedge takee(e, s_2)$

Then 2:

$\big(\lambda Q.\, \exists y.\, Course(y) \wedge Q(y)\big)$

$\big(\lambda s_2.\, \forall x.\, Student(x) \rightarrow \exists e.\, took(e) \wedge taker(e, x) \wedge takee(e, s_2)\big)$

$= \exists y.\, Course(y) \wedge \forall x.\, Student(x) \rightarrow \exists e.\, took(e) \wedge taker(e, x) \wedge takee(e, y)$

Compositional Rules

We also need new rules with semantic attachments for our quantifiers:

- Composing quantifier with N is now modifying the *inside* part of a store
- An NP now introduces a new index variable, which is wrapped in a lambda expression

A Course

NP $\lambda u.u(s_1),(\lambda Q.\exists x.Course(x) \wedge Q(x),1)$

Det

a

$\lambda P.\lambda Q.\exists x.P(x) \wedge Q(x)$

N

course

$\lambda x.Course(x)$

Semantic attachment for NP -> Det N:

$\{\lambda u.u(s_i),(Det.sem(N.sem),i)\}$

At-Home Exercise

Finish the derivation for the underspecified representation of *Every student took a course.*

- Will post answer on Ed

Recall:

$VP \rightarrow V\ NP \qquad \{V.sem(NP.sem)\}$

$S \rightarrow NP\ VP \qquad \{NP.sem(VP.sem)\}$

$V \rightarrow took$

$\{\lambda w. \lambda z. w(\lambda x. \exists e. Took(e) \wedge Taker(e, z) \wedge Takee(e, x))\}$

$Det \rightarrow every \qquad \{(\lambda P. \lambda Q. \forall x. P(x) \rightarrow Q(x))\}$

$N \rightarrow student \qquad \{\lambda x. Student(x)\}$