Combining Formal and Distributional Models of Temporal and Intensional Semantics

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Inference with Temporal Senantics

Mike is visiting Baltimore

⇒ *Mike has arrived in Baltimore*

⇒ *Mike will leave Baltimore*

⇏ *Mike has left Baltimore*

Inference with Temporal Senantics

Mike is visiting Baltimore
⇒ *Mike has arrived in Baltimore*
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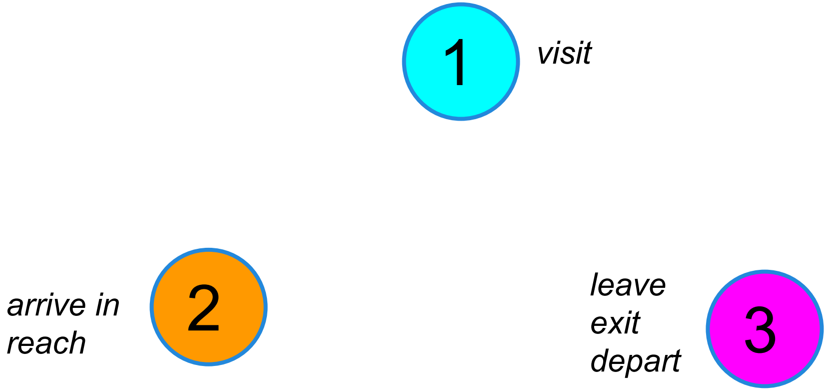
Temporal information can be expressed by both function words and content words

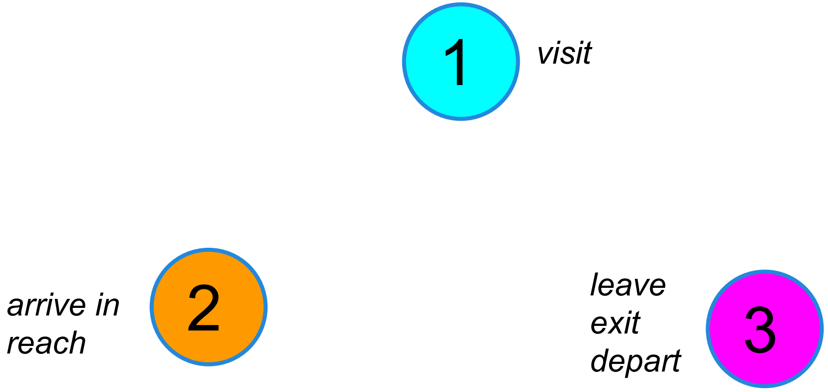
Proposal

- Hand built lexicon for function words
- *Symbolic* content word interpretations from distributional semantics
- CCG for compositional semantics

Combining Distributional and Logical Semantics



Combining Distributional and Logical Semantics



visit $\vdash \lambda x \lambda y \lambda e \,.\, rel1(x,y,e)$

arrive in $\vdash \lambda x \lambda y \lambda e \,.\, rel2(x,y,e)$

reach $\vdash \lambda x \lambda y \lambda e \,.\, rel2(x,y,e)$

leave $\vdash \lambda x \lambda y \lambda e \,.\, rel3(x,y,e)$

Combining Distributional and Logical Semantics

Mike	reached	Baltimore
NP	**(S\NP)/NP**	**NP**
mike	*λyλxλe .* rel2*(x,y,e)*	*baltimore*

S\NP

λxλe . rel2*(x, baltimore)*

S

λe . rel2*(mike, baltimore, e)*

Combining Distributional and Logical Semantics

Mike arrived in Baltimore

⇓

rel2(*mike, baltimore, e*)

⇒ ***Mike reached Baltimore***

⇓

rel2(*mike, baltimore, e*)

Combining Distributional and Logical Semantics

Mike	didn’t	reach	Baltimore
NP	**(S\NP)/(S\NP)**	**(S\NP)/NP**	**NP**
mike	$\lambda p \lambda x \lambda e.\ \neg p(x,e)$	$\lambda y \lambda x \lambda e\ .\ \mathrm{rel2}(x,y,e)$	*baltimore*

S\NP

$\lambda x \lambda e\ .\ \mathrm{rel2}(x,\ baltimore)$

S\NP

$\lambda x \lambda e\ .\ \neg \mathrm{rel2}(x,\ baltimore,\ e)$

S

$\lambda e\ .\ \neg \mathrm{rel2}(mike,\ baltimore,\ e)$

Combining Distributional and Logical Semantics

Mike didn’t arrive in Baltimore

⇩

$\neg$rel2(*mike, baltimore*)

Mike didn’t reach Baltimore

⇩

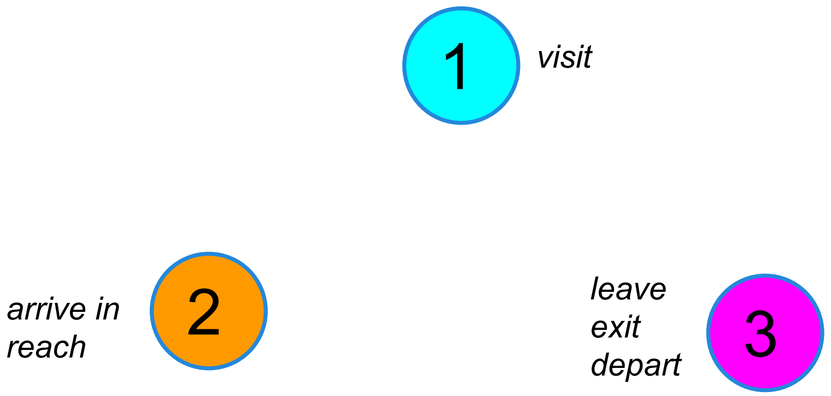
$\neg$rel2(*mike, baltimore*)

Combining Distributional and Logical Semantics

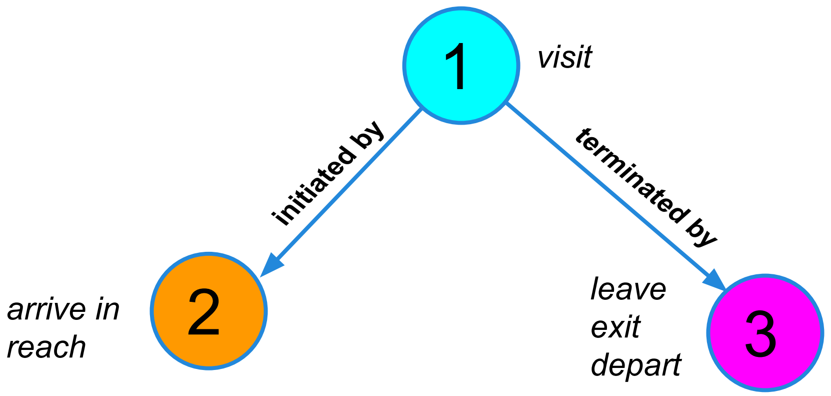
Simple clustering is not enough

- Models words as either synonyms or unrelated
- Many lexical semantic relations: temporal, causal, hypernyms, etc.

Temporal Semantics

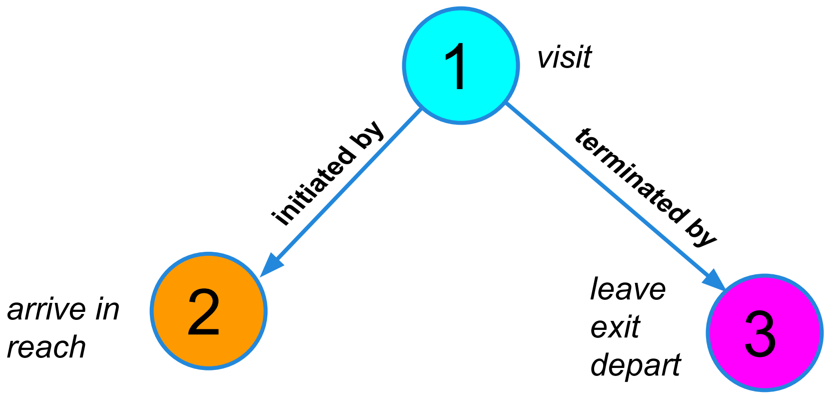


Temporal Semantics



Learn graph structures capturing relations between events
Similar to *Scaria et al. (2013)*

Temporal Semantics

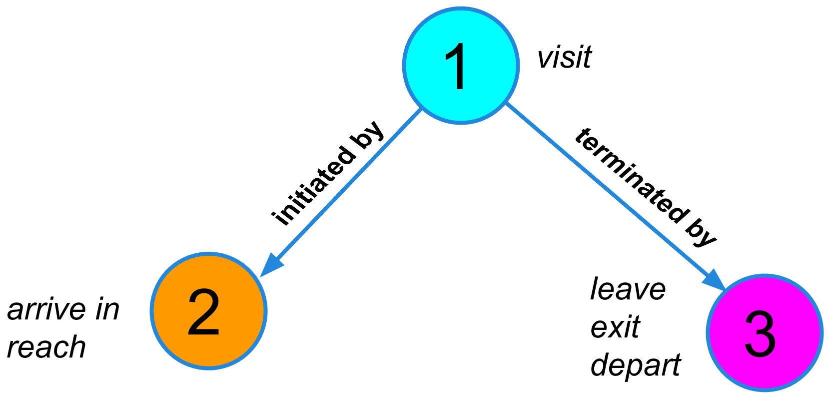


arrive in ⊢ λxλyλe . rel2(x,y,e)

reach ⊢ λxλyλe . rel2(x,y,e)

leave ⊢ λxλyλe . rel3(x,y,e)

Temporal Semantics



visit $\vdash \lambda x \lambda y \lambda e \,.\, rel1(x,y,e) \wedge$
$\exists e'[rel2(x,y,e') \wedge before(e,e')]$
$\exists e''[rel3(x,y,e'') \wedge after(e,e'')]$

Temporal Semantics

Hand-build lexical entries for auxiliary verbs, using same temporal relations:

has $\vdash \lambda p \lambda x \lambda e \,.\, \textit{before}(r, e) \wedge p(x, e)$

will $\vdash \lambda p \lambda x \lambda e \,.\, \textit{after}(r, e) \wedge p(x, e)$

is $\vdash \lambda p \lambda x \lambda e \,.\, \textit{during}(r, e) \wedge p(x, e)$

used $\vdash \lambda p \lambda x \lambda e \,.\, \textit{before}(r, e) \wedge p(x, e) \wedge$
$\neg \exists e'[\textit{during}(r, e) \wedge p(x, e')]$

Temporal Semantics

Mike	will	leave	Baltimore
NP	**(S\NP)/(S\NP)**	**(S\NP)/NP**	**NP**
mike	$\lambda p \lambda x \lambda e.\ p(x,e) \wedge after(r,e)$	$\lambda y \lambda x \lambda e\ .\ rel3(x,y,e)$	*baltimore*

S\NP

$\lambda x \lambda e\ .\ rel3(x, baltimore)$

S\NP

$\lambda x \lambda e\ .\ rel3(x, baltimore, e) \wedge after(r,e)$

S

$\lambda e\ .\ rel3(mike, baltimore, e) \wedge after(r,e)$

Temporal Semantics

Mike is visiting Baltimore

$\exists e[rel1(mike, baltimore, e) \land during(r,e)]$

$\land \ \exists e'[rel2(mike, baltimore, e') \ \land before(e,e')] \ \land$

$\land \ \exists e''[rel3(mike, baltimore, e) \land after(e'',e)]$

Temporal Semantics

Mike is visiting Baltimore

$\exists e[rel1(mike, baltimore, e) \wedge during(r,e)]$

$\wedge\ \exists e'[rel2(mike, baltimore, e') \wedge before(e,e')] \wedge$
$\wedge\ \exists e''[rel3(mike, baltimore, e) \wedge after(e'',e)]$

⇒ ***Mike will leave Baltimore***

$\exists e[rel3(mike, baltimore, e) \wedge after(r,e)]$

Intensional Semantics

Mike set out for Baltimore

⇒ Mike tried to reach Baltimore

⇒ Mike headed to Baltimore

⇏ Mike reached Baltimore

Intensional Semantics

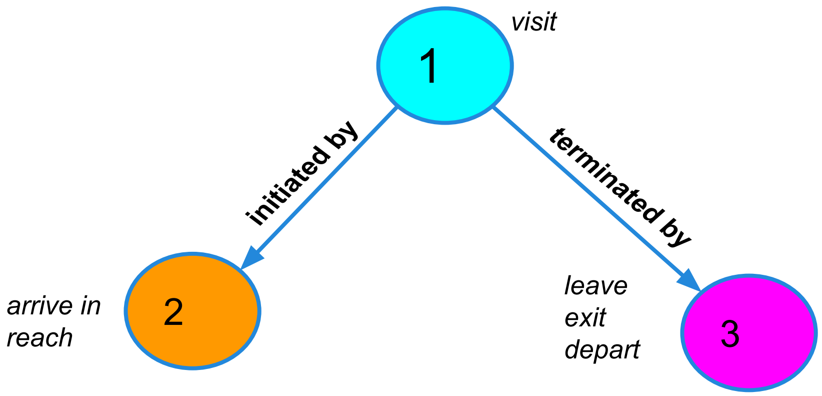
Mike failed to reach Baltimore

⇒ Mike tried to reach Baltimore

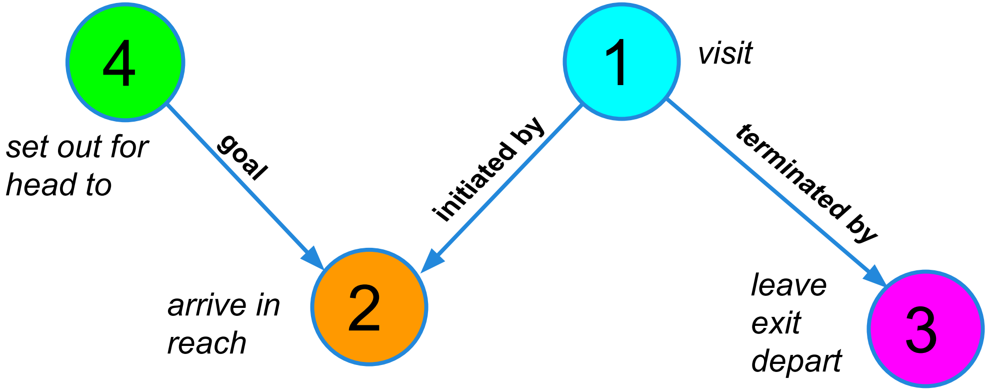
⇒ Mike headed to Baltimore

⇒ Mike didn’t reach Baltimore

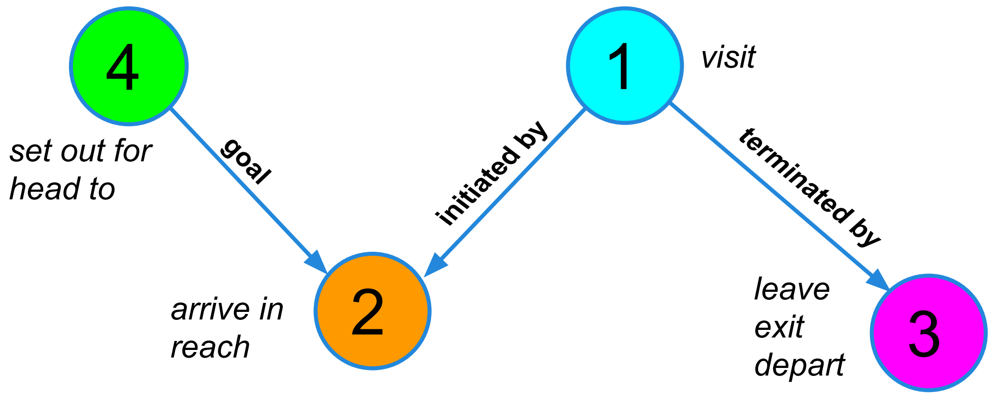
Temporal Semantics



Intensional Semantics



Intensional Semantics



set out for $\vdash$ λxλyλe . rel4(x,y,e) ∧ ◊ ∃ e’[rel2(x,y,e’) ∧ goal(e,e’)]

Intensional Semantics

try $\vdash$ $\lambda p \lambda x \lambda e.\ \exists e'[goal(e, e') \wedge \Diamond p(x, e')]$

Intensional Semantics

try $\vdash$ $\lambda p \lambda x \lambda e.\ \exists e'[\text{goal}(e, e') \wedge \Diamond p(x, e')]$

fail $\vdash$ $\lambda p \lambda x \lambda e.\ \exists e'[\text{goal}(e, e') \wedge \Diamond p(x,e')] \wedge$
$\neg \exists e''[\text{goal}(e, e'') \wedge p(x, e'')]$

Intensional Semantics

Mike set out for Baltimore

$\exists e[rel4(x,y,e) \wedge \Diamond \exists e'[rel2(mike, baltimore,e') \wedge goal(e,e')]$

⇒ *Mike tried to reach Baltimore*

$\Diamond \exists e'[rel2(mike, baltimore, e') \wedge goal(e,e')]$

Evaluation

Conclusions

- Many inferences rely on complex interaction of formal and lexical semantics

- Recent work gives us the tools to incorporate more linguistics into computational semantics