Inferring Meaning From Disfluencies in an Incremental Dialogue Framework

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Universität Bielefeld

1. Problem statement
2. Incremental dialogue framework: IU, DS-TTR and DyLan
3. Parsing disfluency
4. Probability and Order-theoretic Semantics
5. Interpreting disfluency in a dialogue system

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Disfluency and other ‘dirty’ stuff

- Real dialogue is full of things like:
  - Filled pauses
  - Fillers (discourse markers, edit terms)
  - Self-repairs
  - Unfilled pauses (i.e. mid-turn silence/hesitation)
  - Laughter
  - Laughed speech
  - Exclamations (oh!, damn!, s***!)

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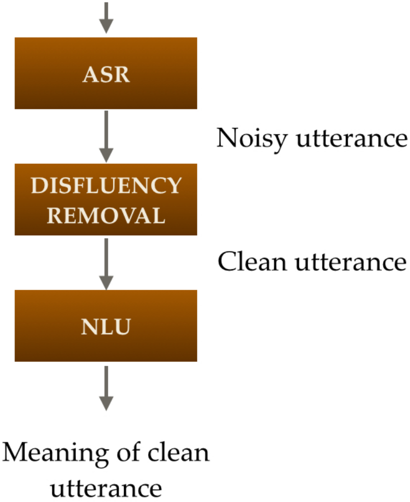
  - Exclamations (oh!, damn!, s***!)
- Are these problems, or *solutions*? [Clark, 1996]
- What do they *mean* in dialogue?

Disfluency processing: why do we care?

Dialogue systems (parsing speech)



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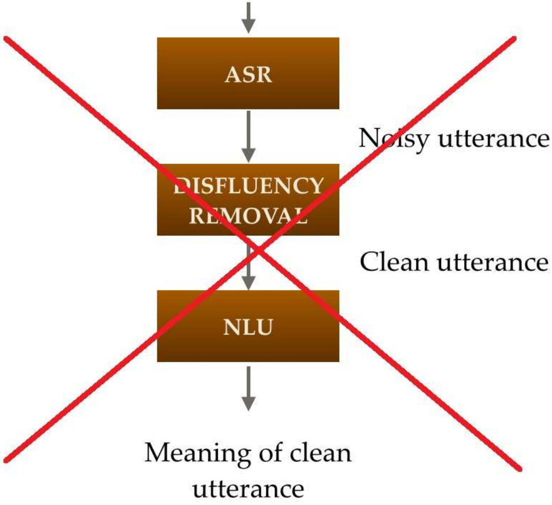

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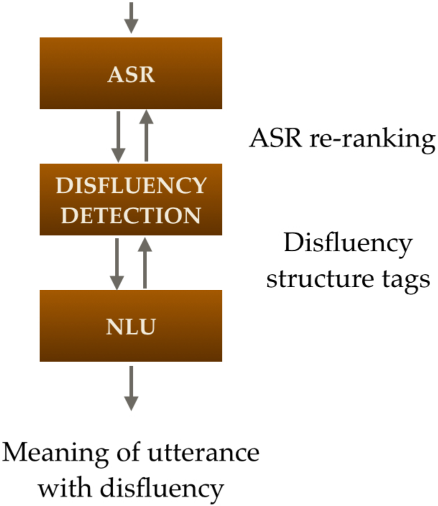


Self-repairs

"But one of **the, the** two things that I'm really..."

"Our situation is **just a little bit, kind of the** opposite of that"

"and you know it's like **you're, I mean,** employments are contractual by nature anyway"

[Switchboard examples]

Self-repairs: Annotation scheme

$$\text{John} \quad [\ \underbrace{\text{likes}}_{\text{reparandum}} \ + \ \underbrace{\{\text{uh}\}}_{\text{interregnum}} \ \underbrace{\text{loves}}_{\text{repair}}\ ]\ \text{Mary}$$

[Shriberg, 1994, onwards]

Terminology: *edit terms*, *interruption point* (+), *repair onset*

Self-repairs: classes

"But one of [the, + the] two things that I'm really..."

[repeat]

"Our situation is just [a little bit, + kind of the opposite] of that"

[substitution]

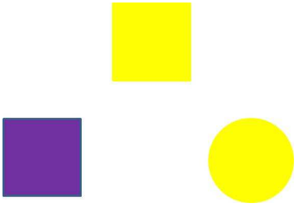
"and you know it's like [you're + {I mean}] employments are contractual by nature anyway"

[delete]

[Switchboard examples]

A familiar psycholinguistic experiment

- [Brennan and Schober, 2001]
  'Pick the yell-, uhh, purple square'



A familiar psycholinguistic experiment

- [Brennan and Schober, 2001] subjects use the reparandum and the presence of fillers to help make faster reference decisions:

  "Pick the, uh, purple square" *faster than fluent, no less accurate.*

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- "Pick the purple square, no, yellow" [Levelt, 1989, Ginzburg et al., 2014] *elliptical interpretation*

SUMMARY: what needs to be addressed...

- **Interpretation**: lack of fully incremental processing account of repairs. Deletion/ignoring of reparandum in self-repairs in automatic approaches. Lacks interface to discourse model.

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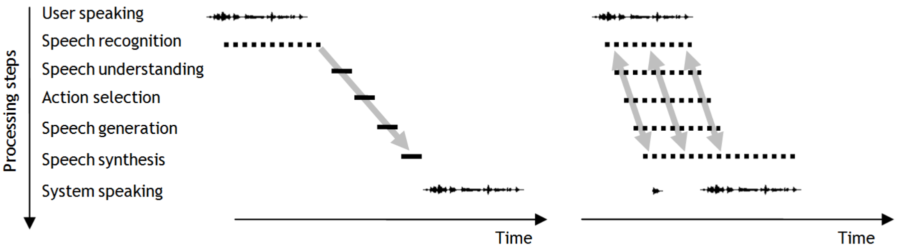
SUMMARY: what needs to be addressed...

- **Interpretation**: lack of fully incremental processing account of repairs. Deletion/ignoring of reparandum in self-repairs in automatic approaches. Lacks interface to discourse model.
- **Generation**: lack of full integration with dialogue manager (incremental access to representations and discourse model)- needs inter-changeability with parsing.
- **Dialogue models/dialogue management**: a nice model of forward and backward looking disfluency [Ginzburg et al., 2014], but lack of integration with incremental semantic grammars, parsers and generators.

  Needs probabilistic information to model realistic dialogue situations (*relevance*)

Incrementality (1 kind)

Non-incremental vs. Incremental Dialogue Systems



[Schlangen and Skantze, 2011]

DyLan Incremental stuff at all levels

Dynamic Syntax + TTR + IU Framework/Jindigo

[Purver et al., 2011]

- An incremental grammar formalism
  - *Dynamic Syntax* [Kempson et al., 2001]
- Interface between incremental representations and domain semantics
  - *Type Theory with Records (TTR)* [Cooper, 2005]
- An incremental dialogue framework which can store procedural context
  - *Incremental Unit (IU)* framework [Schlangen and Skantze, 2009]

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Dynamic Syntax + TTR + IU Framework/Jindigo + Lattice and probability theory

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- An incremental dialogue framework which can store procedural context
  - *Incremental Unit (IU)* framework [Schlangen and Skantze, 2009]
- A dialogue model providing likelihood and relevance measures
  - *Lattice theory inquiry calculus* [Knuth, 2005] and Probabilistic TTR [Cooper et al., 2014]

TTR

$s : T$

where s can be a record and T can be a record type [Cooper, 2005] with fields of type judgements

- RTs are *inhabited* or *witnessed* by records

TTR

$$R_1 = \begin{bmatrix} l_1 & : & T_1 \\ l_2 & : & T_2 \\ l_3 & : & T_3(l_1) \end{bmatrix} \quad R_2 = \begin{bmatrix} l_1 & : & T_1 \\ l_2 & : & T_{2'} \end{bmatrix} \quad R_3 = []$$

Figure : Example TTR record types

TTR

$$S_1 = \begin{bmatrix} l_1 & = & a \\ l_2 & = & b \\ l_3 & = & c \end{bmatrix} \quad S_2 = \begin{bmatrix} l_1 & = & a \\ l_2 & = & b' \end{bmatrix} \quad S_3 = []$$

Figure : Example TTR records

Record type check:
For a record s and and record type R, $s : R$ is true iff for every field $\left[\ l\ :\ T\ \right]$ in R there is a field $\left[\ l\ =\ v\ \right]$ in s such that $v : T$.

Subtype relation check:
For record types R_1 and R_2, $R_1 \sqsubseteq R_2$ is true iff for each field $\left[\ l\ :\ T_2\ \right]$ in R_2 there is a field $\left[\ l\ :\ T_1\ \right]$ in R_1 such that $T_1 \sqsubseteq T_2$. The $\sqsubseteq$ relation is reflexive and transitive.

DS-TTR

- Recent DS variant uses TTR *record types* on the trees [Purver et al., 2011].
- Record type compilation for *partial trees* [Hough, 2011] allows strong incremental interpretation [Milward, 1991].
- Incrementally constructed structures can be compared to domain concepts in word-by-word *subtype* relation checking.
- In generation, a goal tree in DS generation [Purver and Kempson, 2004] can be a TTR *goal concept* (record type) [Hough, 2011]- less tied to DS, interface with dialogue state possible.

Parsing *Robin arrives*:

Incremental DS-TTR parsing

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$$\begin{bmatrix} x & : & e \\ p & : & t \end{bmatrix}$$

Incremental DS-TTR parsing

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Robin

$$\begin{bmatrix} x_{=robin} & : & e \\ p & : & t \end{bmatrix}$$

Incremental DS-TTR parsing

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$$\left[\begin{array}{lll} x_{=robin} & : & e \\ p_{=arrive(x)} & : & t \end{array}\right]$$

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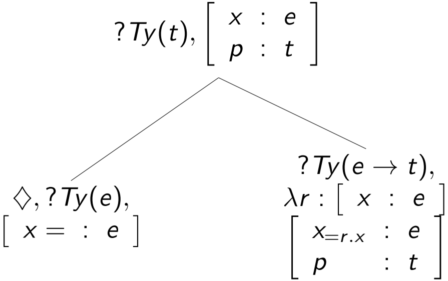

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$$?Ty(t), \left[\begin{array}{lcl} x_{=robin} & : & e \\ p & : & t \end{array}\right]$$

$$\Diamond, Ty(e), \left[\begin{array}{lcl} x =_{robin} & : & e \end{array}\right]$$

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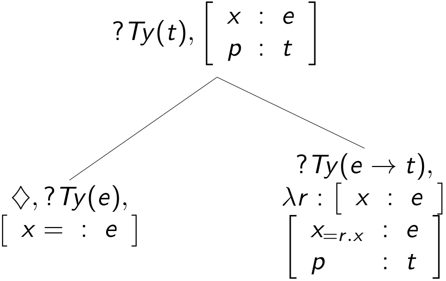

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MATCHES!

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DyLan dialogue system

- `DyLan` NLU [Purver et al., 2011] and NLG [Hough, 2011] modules in Jindigo [Skantze and Hjalmarsson, 2010], based on the IU framework [Schlangen and Skantze, 2009]
- Uses the graph-based input and output buffers.
- Uses a DS-TTR parsing DAG, shared by generation and parsing
- The notions of *GroundedIn* links to IUs in different modules, can *add*, *commit*, and *revoke* IUs.

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- The notions of *GroundedIn* links to IUs in different modules, can *add*, *commit*, and *revoke* IUs. Gives us the requisite *incremental representation* for any given substring ('repairables').

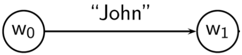
DyLan dialogue system

- **NLU module**:
  - *Input IUs:* Word graph from ASR
  - *Processing:* Increments a DS-TTR parsing DAG, GroundedIn corresponding word IUs
  - *Output IUs:* TTR record types (concepts) to dialogue manager, GroundedIn corresponding IUs of the DS-TTR DAG

DyLan parsing

John

WORD GRAPH
(INPUT)

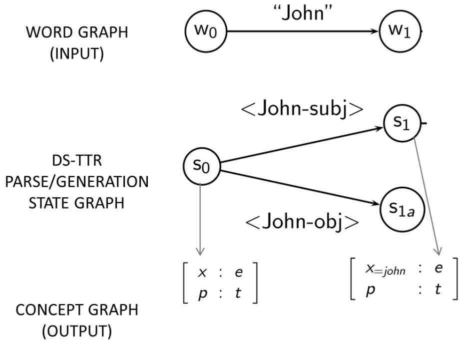


DS-TTR
PARSE/GENERATION
STATE GRAPH

CONCEPT GRAPH
(OUTPUT)

DyLan parsing

John



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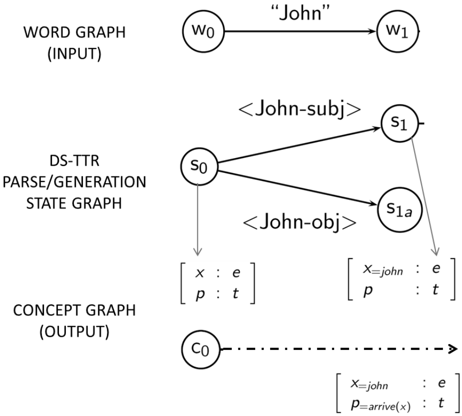
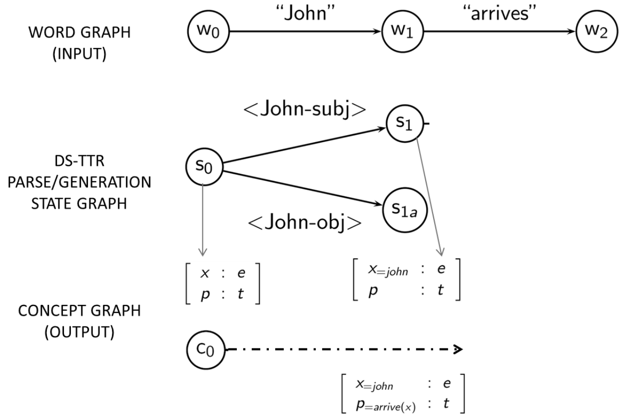


DyLan parsing

John arrives



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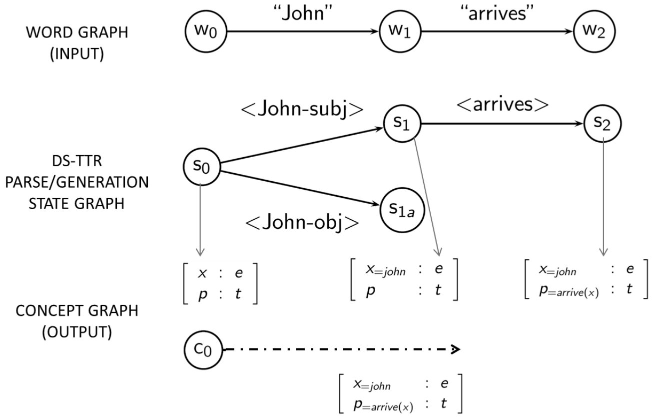

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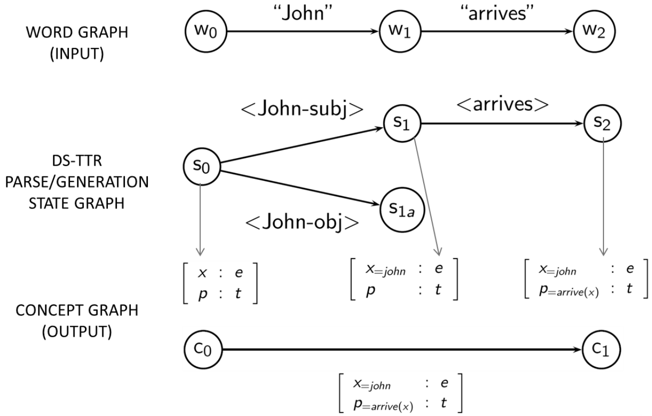

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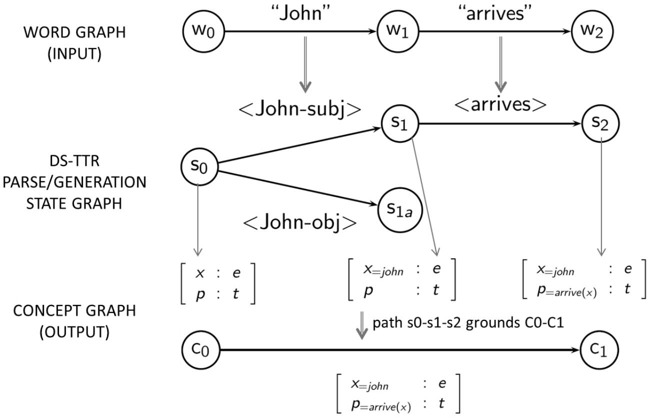
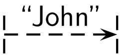
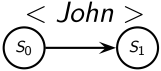
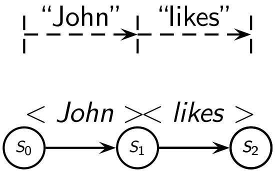






$$\left[\begin{array}{lcl} \text{cont} & = & \left[\begin{array}{lcl} x1 & : & e \\ x_{=John} & : & e \\ e & : & e_s \\ p_{=subj(e,x)} & : & t \end{array}\right] \\ \text{ctxt} & = & [Assert(User, \text{cont})] \end{array}\right]$$



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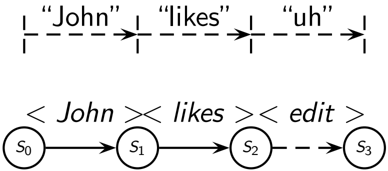

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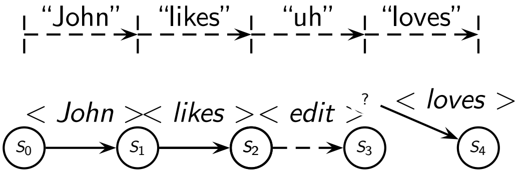

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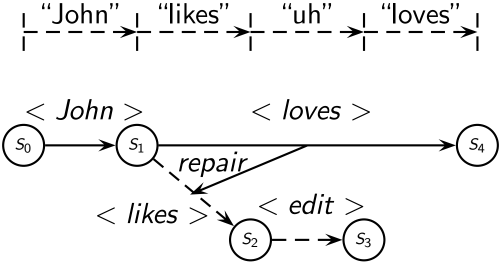

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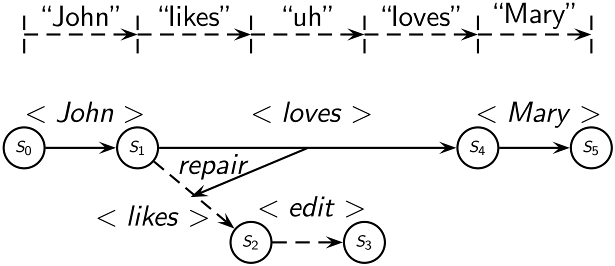

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Model: Where we're up to

- We have strong incremental interpretation and incremental representation [Milward, 1991] of repairs and edit terms
- Models forward looking and backward looking disfluency [Ginzburg et al., 2014]
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- No reasoning/discourse system- just simple matching of domain concept RTs
- We have the 'closed-world' view that parseablility is {false,true}
- Probabilistic reasoning? At which 'level'?

Probabilistic TTR

$s : T = \{0, 1\}$

[Cooper, 2005]

Probabilistic TTR

$p(s : T) = [0, 1]$

[Cooper et al., 2014]

Order theory essentials

- An ordering relation on a set of elements of form $x \leq y$ means 'y includes x'.

  If order defined between some pairs of elements: a partial order (*poset*).
- *Meet*, the greatest lower bound ($\wedge$) and *join*, the least upper bound ($\vee$) of two elements.

Order theory essentials

A poset with all elements closed under meet and join is a *lattice*.

Top ($\top$) and bottom ($\bot$) elements.

Complement of an element $\neg x$ such that:

$$x \wedge \neg x = \bot$$
$$x \vee \neg x = \top$$

Atoms are elements that cover (direct successors of) $\bot$.

Join-irreducible elements those not definable by join of two other elements.

Order theory essentials

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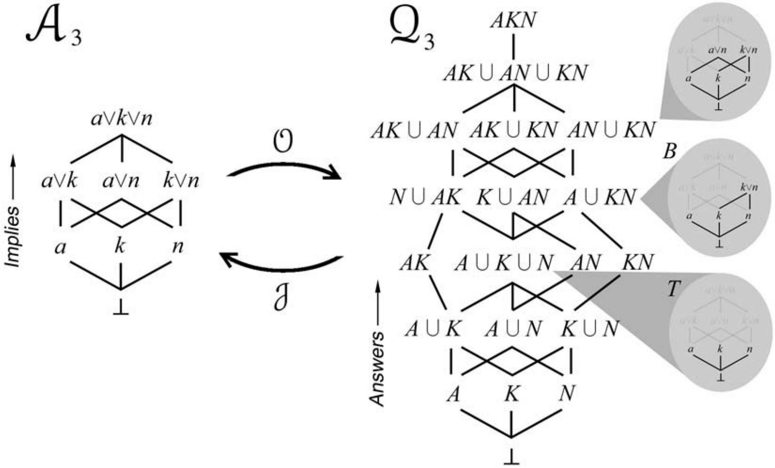
Join-irreducible elements those not definable by join of two other elements.

Distributed lattices can express any poset of sets ordered by the $\subset$ relation. Obey distributivity relations.

Complemented lattices express any lattice where every element x has a unique complement $\neg x$.

Previous work: Probability theory and lattices (Knuth)



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- Boolean operators $\wedge$ and $\vee$ and $\neg$ happily coincide with the order-theoretic relations
- Derives probabilities from function on the lattice $Z(x, y)$, the degree to which x includes/implies y:

$$p(x \mid y) = Z(x, y) = \begin{cases} 1 & \text{if } y \rightarrow x \\ 0 & \text{if } x \wedge y = \perp \\ p & \text{otherwise, where } 0 \leq z \leq 1 \end{cases}$$

- Normal probability theory applies: sum rule, product rule, Bayes theorem

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- Knuth's *Inquiry Calculus* generalises Boolean logic to probability and information theory through *distributed lattices*
- Boolean operators $\wedge$ and $\vee$ and $\neg$ happily coincide with the order-theoretic relations
- Derives probabilities from function on the lattice $Z(x, y)$, the degree to which x includes/implies y:

$$p(x \mid y) = Z(x, y) = \begin{cases} 1 & \text{if } y \rightarrow x \\ 0 & \text{if } x \wedge y = \bot \\ p & \text{otherwise, where } 0 \leq z \leq 1 \end{cases}$$

- Normal probability theory applies: sum rule, product rule, Bayes theorem
- Question lattice: a question's *relevance* to the central issue

Record Type lattices

- RT lattice G ordered by the relation ‘is a subtype of’ $x \sqsubseteq y$
- Meet is maximal common subtype $x \dot{\wedge} y$
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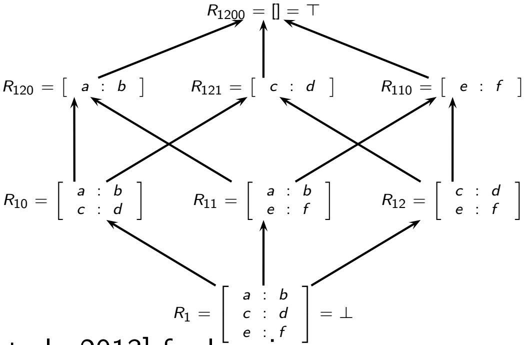
Record Type lattices

- RT lattice G ordered by the relation 'is a subtype of'
  $x \sqsubseteq y$
- Meet is maximal common subtype $x \curlywedgedot y$
- Join is minimal common supertype $x \curlyveedot y$
- Guaranteed to be *distributive* as long as it has a $\bot$ and $\top$, often the empty type [ ], not generally *complemented*

$$x \curlywedgedot (y \curlyveedot z) = (x \curlywedgedot y) \curlyveedot (x \curlywedgedot z) \quad \text{(D1. Distributivity of } \curlywedgedot \text{ over } \curlyveedot \text{)}$$
$$x \curlyveedot (y \curlywedgedot z) = (x \curlyveedot y) \curlywedgedot (x \curlyveedot z) \quad \text{(D2. Distributivity of } \curlyveedot \text{ over } \curlywedgedot \text{)}$$

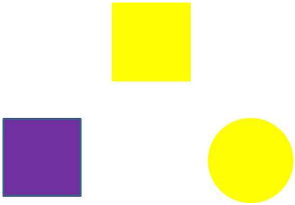
Record Type lattices



[Eshghi et al., 2013] for learning

A familiar psycholinguistic experiment

- [Brennan and Schober, 2001]
  'Pick the yell-, uh, purple square'



A familiar psycholinguistic experiment

Disjunction of final situations are *the atoms*.

Overall probability mass in lattice L is $P(L)$ global denominator.

$$\begin{bmatrix} x & : & ind \\ col_p & : & purple(x) \\ shp_{sq} & : & square(x) \end{bmatrix} \frac{\|PSq\|}{P(L)} \qquad \begin{bmatrix} x & : & ind \\ col_y & : & yellow(x) \\ shp_{sq} & : & square(x) \end{bmatrix} \frac{\|YSq\|}{P(L)} \qquad \begin{bmatrix} x & : & ind \\ col_y & : & yellow(x) \\ shp_c & : & circle(x) \end{bmatrix} \frac{\|YC\|}{P(L)}$$

$$\bot = 0$$

A familiar psycholinguistic experiment

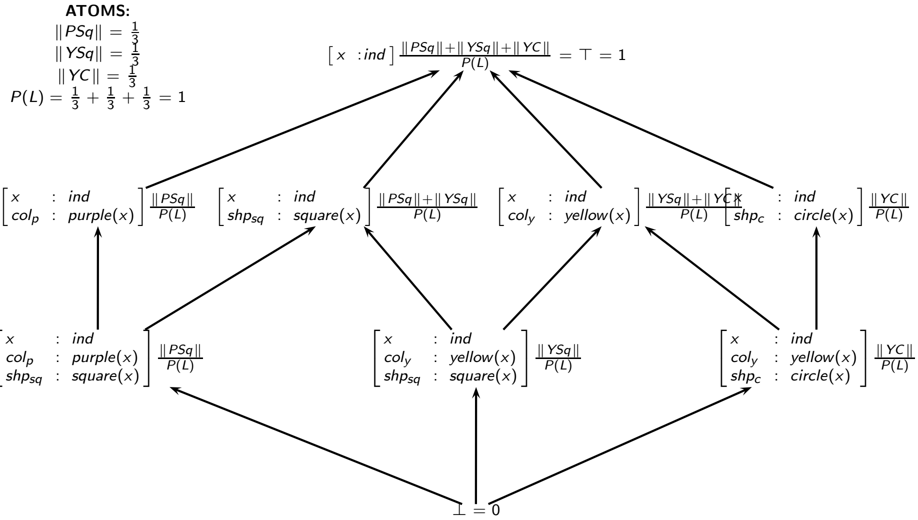


Figure : Record type lattice with initial uniform prior probablities

A familiar psycholinguistic experiment

ATOMS:

$\|PSq\| = \frac{1}{3}$

$\|YSq\| = \frac{1}{3}$

$\|YC\| = \frac{1}{3}$

$P(L) = \frac{1}{3} + \frac{1}{3} + \frac{1}{3} = 1$

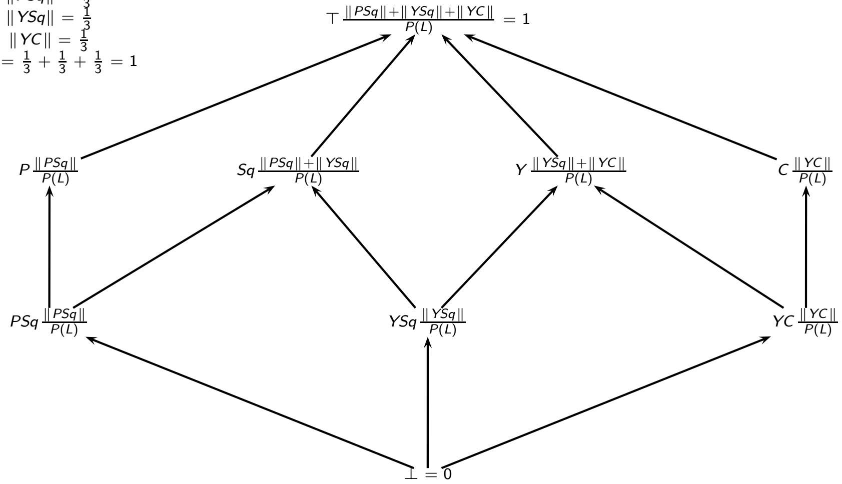
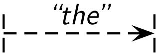
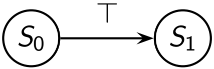


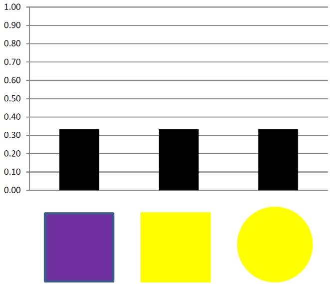
Figure : Record type lattice with initial uniform prior probablities

Self-repair:
IF parse(W) at vertex S_n unlikely OR IF $p(s : R_x \mid W)$ for $R_x \in G$ is unlikely
THEN (1) backtrack: parse(W) from vertex S_{n-1}. IF successful (2) `add` a new edge to the top path ELSE set $n = n - 1$ and repeat (1).

Interpreting disfluencies incrementally







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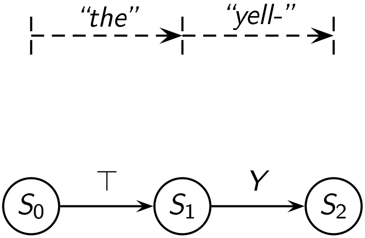

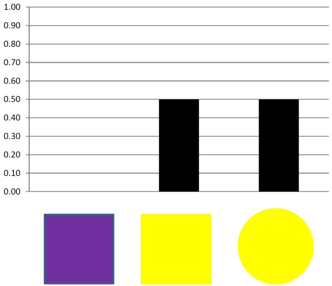

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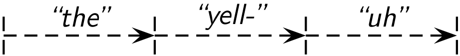

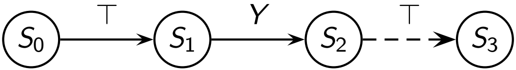

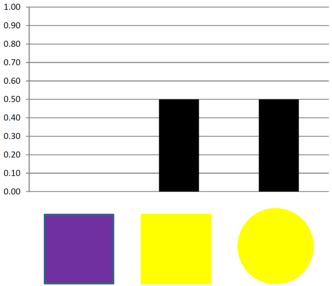

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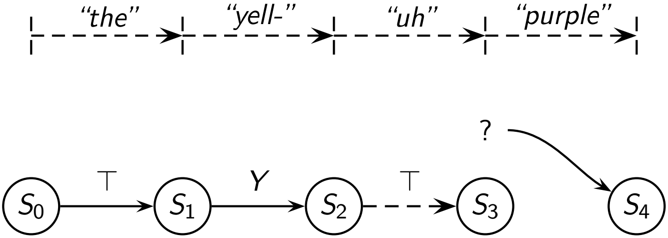

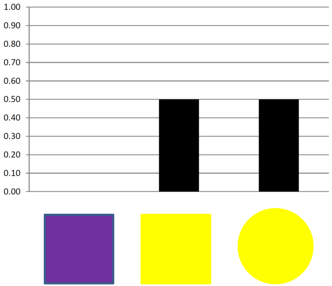

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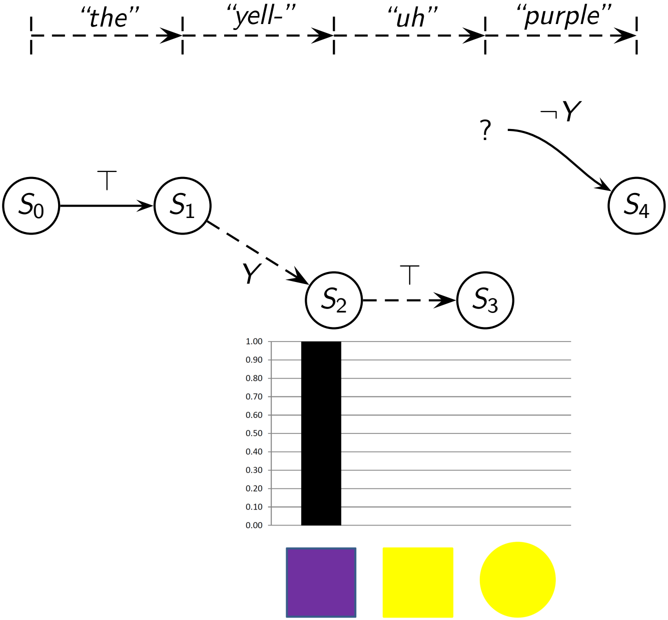

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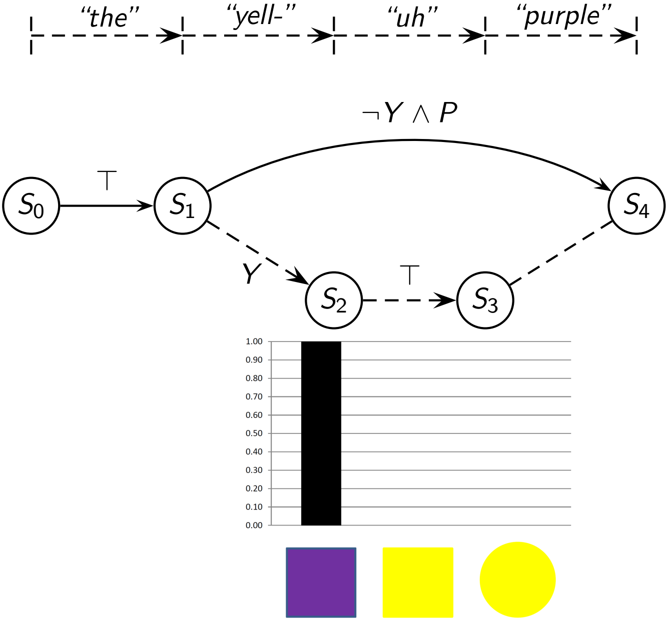

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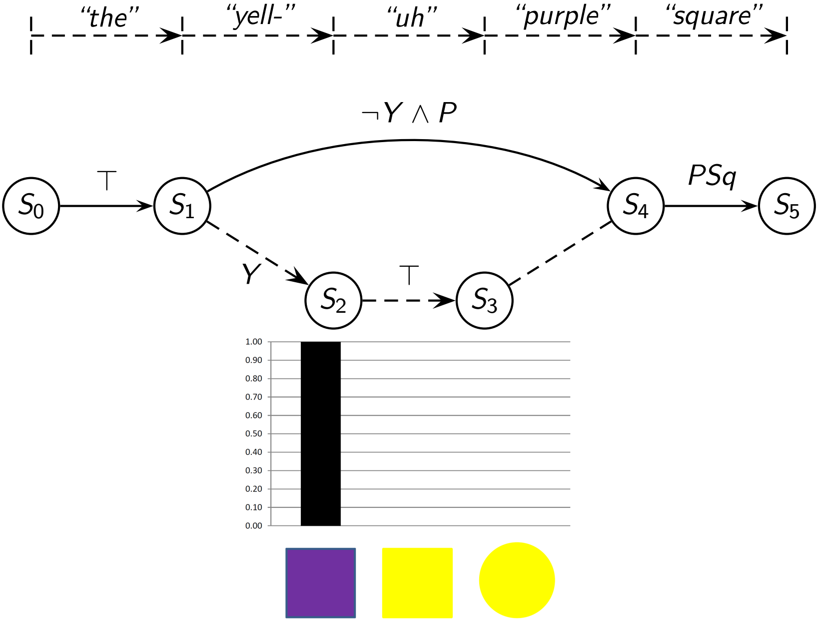

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Conclusion: Disfluency and other ‘dirty’ stuff

- Real dialogue is full of things like:
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- The DUEL project will tell us!

Thanks!

especially to:

- Matt Purver
- DUEL project (Bielefeld University and Paris 7, DFG and ANR)

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