Combining TTR and game theory in dialogue modelling

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Outline

Games in a theory of language as action

Games in TTR

Social meaning games in GT

Argument games using topoi

Topoi and personae

A probabilistic model of topoi as social signals

Outline

Language as action

- Language as action (Austin, 1962; Lewis, 1969; Clark, 1996; Barwise and Perry, 1983)
- Agents need to coordinate action: coordination games (Lewis, 1969)

Two kinds of games

- Dialogue games build on techniques used in coordination games involving non-linguistic agents
- *Interaction games* in TTR, a type theory with records (Cooper, 2014; Breitholtz, 2014; Cooper, in prep)
- *Social meaning games* Burnett (2019), drawing on techniques from Game Theory (GT) Lewis (1969)
- Combining these types of games in terms of a theory of dialogue involving *Information State Update*: Ginzburg's *KoS* (Ginzburg, 2012)

Outline

Games in TTR

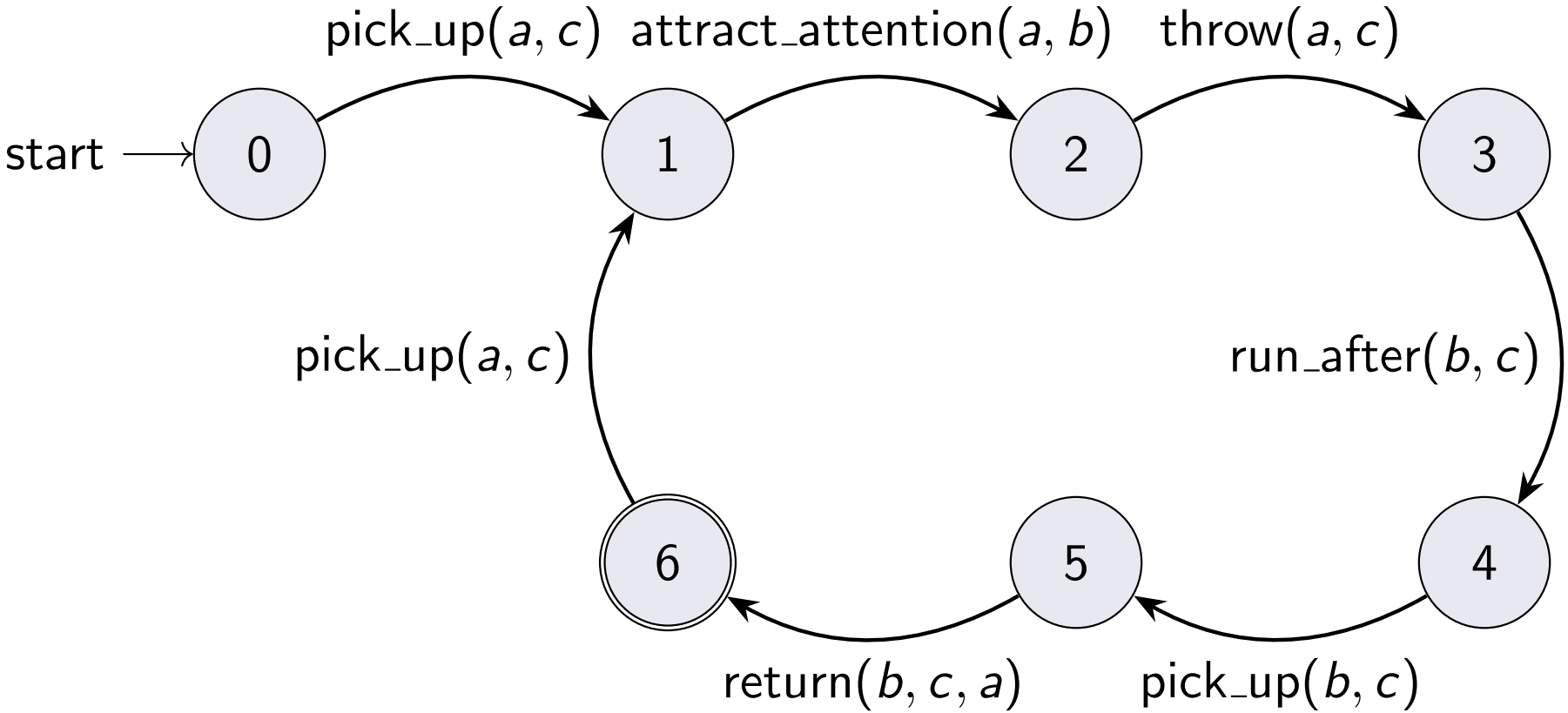
- Cooper (in prep), Ch. 1 (discussed here)
- Breitholtz (2014) in relation to enthymematic reasoning
- related to Ginzburg on genre and conversation types

String types

cf. work by Tim Fernando, e.g. Fernando (2015)

1. if T_1, $T_2 \in$ **Type**, then $T_1 ^\frown T_2 \in$ **Type**
   $a : T_1 ^\frown T_2$ iff $a = x ^\frown y$, $x : T_1$ and $y : T_2$
2. if $T \in$ **Type** then $T^+ \in$ **Type**.
   $a : T^+$ iff $a = x_1 ^\frown \ldots ^\frown x_n$, $n > 0$ and for i, $1 \leq i \leq n$, $x_i : T$
   ...

A game of fetch



$$(\text{pick\_up}(a,c)^\frown\text{attract\_attention}(a,b)^\frown\text{throw}(a,c)^\frown\text{run\_after}(b,c)^\frown \text{pick\_up}(b,c)^\frown\text{return}(b,c,a))^+$$

Information states and gameboards

- Information states (gameboards) are used by agents to keep track of where they are in the creation of an event belonging to a certain type
- each agent has their own view of the state of the game
- plays an essential role in coordination
- *information state* (Larsson, 2002) and *gameboard* (Ginzburg, 1994, 2012, originally Lewis, 1979) are adopted from the literature on dialogue
- we shall model information states as records and use 'gameboard' to refer to types of information states

The types *InfoState* and *InitInfoState*

$$\begin{array}{rl} \mathit{InfoState} & \left[\ \text{agenda} \quad : \quad [\mathit{RecType}]\ \right] \\ \mathit{InitInfoState} & \left[\ \text{agenda}{=}[] \quad : \quad [\mathit{RecType}]\ \right] \end{array}$$

Game of fetch (human, a, dog, b, and stick, c)

- game as a set of update functions corresponding to transitions in a finite state automaton
- an initial update function
  $\lambda r{:}\left[\text{agenda}{=}[]{:}[\mathit{RecType}]\right]$.
  $\left[\text{agenda}{=}[\left[\text{e:pick\_up}(a,c)\right]]{:}[\mathit{RecType}]\right]$
- a non-initial, non-final update function
  $\lambda r{:}\left[\text{agenda}{=}[\left[\text{e:pick\_up}(a,c)\right]]{:}[\mathit{RecType}]\right]$
  $\lambda e{:}\left[\text{e:pick\_up}(a,c)\right]$.
  $\left[\text{agenda}{=}[\left[\text{e:attract\_attention}(a,b)\right]]{:}[\mathit{RecType}]\right]$
- a final update function
  $\lambda r{:}\left[\text{agenda}{=}[\left[\text{e:return}(b,c,a)\right]]{:}[\mathit{RecType}]\right]$
  $\lambda e{:}\left[\text{e:return}(b,c,a)\right]$.
  $\left[\text{agenda}{=}[]{:}[\mathit{RecType}]\right]$

Game of fetch (with roles abstracted)

$$\lambda r^*{:}\begin{bmatrix} \mathsf{h} & : & \mathit{Ind} \\ \mathsf{c}_{\mathrm{human}} & : & \mathsf{human(h)} \\ \mathsf{d} & : & \mathit{Ind} \\ \mathsf{c}_{\mathrm{dog}} & : & \mathsf{dog(d)} \\ \mathsf{s} & : & \mathit{Ind} \\ \mathsf{c}_{\mathrm{stick}} & : & \mathsf{stick(s)} \end{bmatrix} .$$

$$\{\quad \lambda r{:}\big[\mathsf{agenda}{=}[]{:}[\mathit{RecType}]\big] \ .$$
$$\big[\mathsf{agenda}{=}[\big[\mathsf{e{:}pick\_up}(r^*.\mathsf{h},r^*.\mathsf{s})\big]]{:}[\mathit{RecType}]\big],$$
$$\lambda r{:}\big[\mathsf{agenda}{=}[\big[\mathsf{e{:}pick\_up}(r^*.\mathsf{h},r^*.\mathsf{s})\big]]{:}[\mathit{RecType}]\big]$$
$$\lambda e{:}\big[\mathsf{e{:}pick\_up}(r^*.\mathsf{h},r^*.\mathsf{s})\big] \ .$$
$$\big[\mathsf{agenda}{=}[\big[\mathsf{e{:}attract\_attention}(r^*.\mathsf{h},r^*.\mathsf{d})\big]]{:}[\mathit{RecType}]\big],$$
$$\ldots,$$
$$\lambda e{:}\big[\mathsf{e{:}return}(r^*.\mathsf{d},r^*.\mathsf{s},r^*.\mathsf{h})\big] \ .$$
$$\big[\mathsf{agenda}{=}[]{:}[\mathit{RecType}]\big]$$

$$\}$$

Type acts

judgements

specific $o :_A T$ "agent A judges object o to be of type T"

non-specific $:_A T$ "agent A judges that there is some object of type T"

queries

specific $o :_A T?$ "agent A wonders whether object o is of type T"

non-specific $:_A T?$ "agent A wonders whether there is some object of type T"

creations

non-specific $:_A T!$ "agent A creates something of type T"

Action rules

- also known as: licensing conditions, affordances (Gibson, 1979)
- $\underbrace{\varphi_1 \quad \cdots \quad \varphi_n}_{\psi}$
- $\varphi_1, \ldots, \varphi_n$ license/afford ψ
- $\varphi_1, \ldots, \varphi_n$ and ψ are characterized by type acts
- Note: ψ does not *follow* from $\varphi_1, \ldots, \varphi_n$. ψ is just something that is licensed or afforded by $\varphi_1, \ldots, \varphi_n$.

Action rules for Fetch

- $s_{i,A}$ represents A's current information state
- "Execute (contribute to the creation of a witness for) the type on the top of the agenda"
- $$\frac{s_{i,A} :_A \left[\text{agenda:} \begin{bmatrix}\text{fst:}\mathit{RecType} \\ \text{rst:}\mathrm{list}(\mathit{RecType})\end{bmatrix}\right]}{:_A s_{i,A}.\text{agenda.fst!}}$$

Action rules for Fetch, *contd*

- $s_{i+1,A}$ represents A's updated information state
- e^* represents a current event
- f is an update function of the game Fetch.
- "if a move of the game has just been executed put the type of an allowable next move on the agenda"
- $$\frac{f : (T_1 \to (T_2 \to Type)) \quad s_{i,A} :_A T_1 \quad e^* :_A T_2}{s_{i+1,A} :_A f(s_{i,A})(e^*)}$$
- "if you are in a state that can be updated by one of the games update functions without a triggering event, update accordingly"
- $$\frac{f : (T \to Type) \quad s_{i,A} :_A T}{s_{i+1,A} :_A f(s_{i,A})}$$

A problem

What do we do when games are non-deterministic, there is more than one update function that can be applied?

Outline

-ing/-in' variation as social cue

- Use of *-ing/-in'* verbal morphology (Labov, 2012, p. 22, cited by Burnett)
- use of *-ing/-in'* varies depending on context
- Burnett:*-ing/-in'* associated with social and individual characteristcs
  - *-in'* indicates 'friendly', but also possibly 'incompetent'
  - *-ing* indicates 'competent', but also possibly 'aloof'
- combinations of such (perceived) characteristics make up different social *personae*
- key concept in third wave sociolinguistics (Eckert, 2012)

Social meaning games

Burnett (2019)

Definition 4.1. *A **Social Meaning Game** is a tuple* $\langle \{S, L\}, \langle \mathbb{P}, > \rangle, M, C, [\cdot], Pr \rangle$ *where:*

1. *S and L are the players.* Two players
2. *$\langle \mathbb{P}, > \rangle$ is the **universe** (a relational structure), where*
   - *$\mathbb{P} = \{p_1, \ldots, p_n\}$ is a finite set of properties.* Properties such as 'friendly'
   - *$>$ is a relation on $\mathbb{P}$ that is irreflexive.*
3. *M is a finite set of **messages**.* ing/'in
4. *C is a measure function on M describing the **cost** of each message.*
5. *$[\cdot]$ is the **indexation** relation (to be described below).* e.g. 'in is friendly
6. *Pr is a probability distribution over sets of properties describing L's **prior beliefs** about S.* e.g. to what extent does L think Obama is friendly

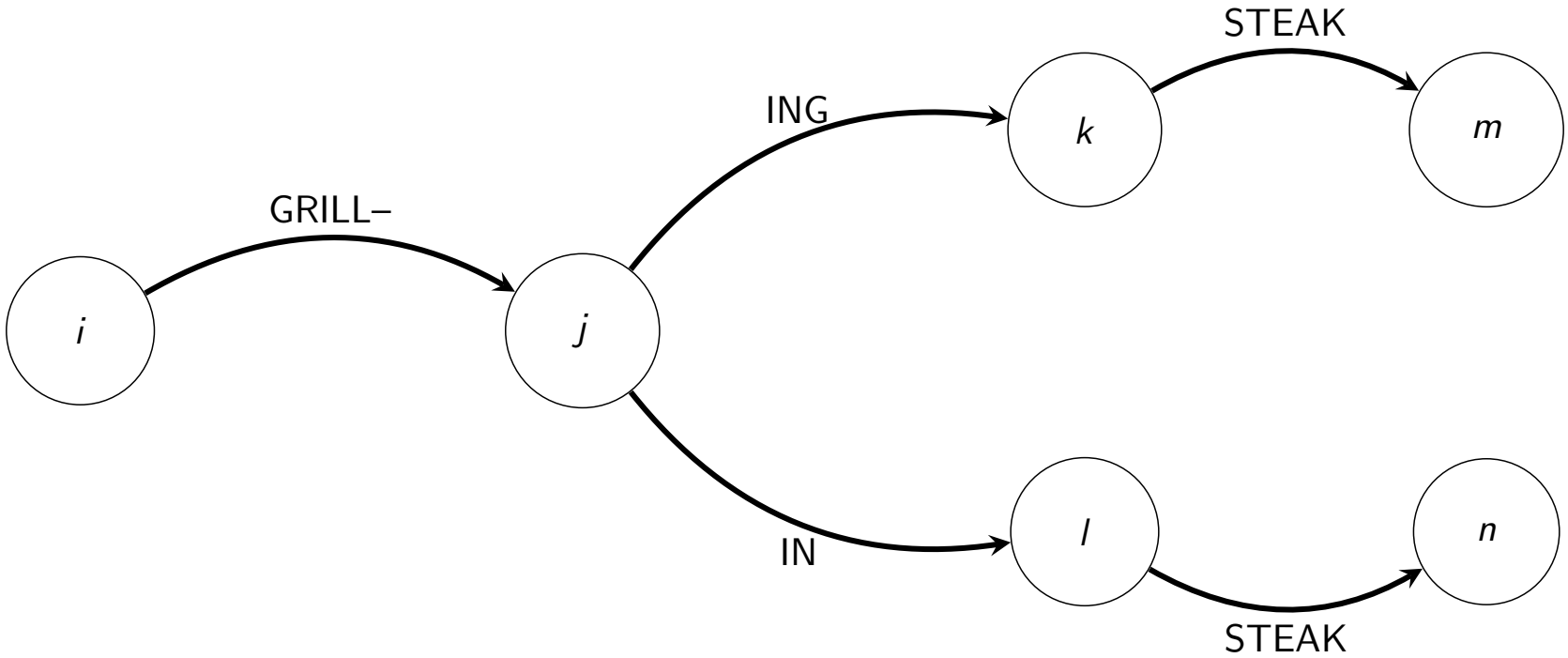
A problem

- Not immediately obvious how such games should be integrated into a general theory of dialogue.
- **Solution:** Embed the games in the kind of information state update/dialogue gameboard approach associated with TTR (Ginzburg, 2012; Cooper and Ginzburg, 2015)

One way of putting TTR and GT together

- For each non-deterministic transition in a TTR game there is a Burnett game to help you make the choice
- That is, if you have more than one update function defined for the current state of the game you need a GT game to choose between them
- The probabilities associated with the different options are computed by a game referring to the mental states of the speaker and addressee as discussed by Burnett.
- Congenial with an information state update (gameboard) approach to dialogue
- *cf.* also HMMs

A simple example: Grilling steak



Outline

Argumentation in dialogue

- Estimating attitudes of addressee when choosing how to make an argument
- Involves estimating prior likelihood of addressee being convinced by a given argument

Our Corpus

- 40 triadic dialogues where participants have been asked to discuss a moral dilemma (Lavelle *et al.*, 2012)
- 20 of these conversations involves a patient diagnosed with schizophrenia

The balloon task

- Subjects asked to discuss a moral dilemma: Four people in a hot air balloon about to crash killing all four unless one of the four is thrown out
- Pilot, 7 months pregnant woman (his wife), doctor (about to find a cure for cancer) and a child prodigy (new Mozart)

Part of a dialogue

- 42 A So I mean the person it seems like the person with least value is the pregnant woman.
- 48 B [she's] pregnant.
- 51 B [So you're] killing two people instead of one.
- 52 C Yhh and another thing is would he be able to pilot the balloon if his wife is overboard?

Two arguments

- if you throw out the pregnant woman, you are killing two people
- if the pregnant woman is thrown out, the pilot (her husband) may not be able to operate the balloon

Enthymemes and Topoi

- Enthymemes = (logically) incomplete arguments
  - the conclusion does not necessarily follow from the premises
  - rely on what is "in the mind" of the listener
- The speaker expects the listener to have access to (and to acknowledge) a particular *topos* (or set of topoi) which warrants the argument. (Aristotle)
- The topoi chosen affect whether the listener will be persuaded or not.
- Enthymemes and/or topoi in conversation (Jackson and Jacobs, 1980; Ducrot, 1988; Anscombre, 1995; Breitholtz, 2014)

Two topoi

- τ_1 there is a choice between sacrificing n and sacrificing m people $m > n \rightarrow$ sacrifice n people
- τ_2 someone is upset $\rightarrow$ they will not be able to perform demanding tasks

Part of a dialogue

- 42 A So I mean the person it seems like the person with least value is the pregnant woman.
- 48 B [she's] pregnant.
- 51 B [So you're] killing two people instead of one. τ_1
- 52 C Yhh and another thing is would he be able to pilot the balloon if his wife is overboard? τ_2

Argument game

- A TTR game (*cf.* suggestion games in Breitholtz (2014))
- Main moves: speaker makes an argument, listener accepts or rejects it
- In order to make an argument you have to first choose an appropriate topos
- Need a GT game

Argument game: choose topos

A tuple $\langle \{S, L\}, T_{cg}, \mathbb{T}, C, \mathfrak{I}, Pr \rangle$ where:

1. S and L are the *players* Two players
2. T_{cg} is a record type representing the *common ground* (*universe*) Type of the balloon situation
3. $\mathbb{T}$ is a finite set of *topoi* which S regards as relevant to the common ground Topoi on which arguments may be based
4. C_S is a measure function on $\mathbb{T}$ Cost of presenting topoi for S
   C_L is a measure function on $\mathbb{T}$ Cost of accepting topoi for L
5. $\mathfrak{I}$ is a relation between members of $\mathbb{T}$ and enthymemes *instantiating* them based on objects introduced in T_{cg}
6. Pr is probability distribution over $\mathbb{T}$ What S regards as topoi most likely to be accepted by L

Calculating the potential utility of using a topos

For $\tau \in \mathbb{T}$, S estimates potential utility of τ

$$\mathit{utility}_S(\tau) = \max(0, \mathit{Pr}(\tau) - C_S(\tau))$$

Payoffs: Actual payoff of τ for both players depending on whether L accepts or rejects

	Accept		Reject	
τ	$1 - C_S(\tau)$	$1 - C_L(\tau)$	0	$C_L(\tau)$

Updating expected probability of L being convinced

Let $\alpha \geq 2$ Temperature constant regulating learning rate

L accepts τ:

$$Pr(\tau) := Pr(\tau) + \frac{1-Pr(\tau)}{\alpha}$$ Increase probability that τ is convincing

$$\forall \tau' \neq \tau Pr(\tau') := Pr(\tau') - \frac{1-Pr(\tau)}{\alpha(|\mathbb{T}|-1)}$$ Decrease probability on other topoi

L rejects τ:

$$Pr(\tau) := Pr(\tau) - \frac{Pr(\tau)}{\alpha}$$ Decrease probability that τ is convincing

$$\forall \tau' \neq \tau Pr(\tau') := Pr(\tau') + \frac{Pr(\tau)}{\alpha(|\mathbb{T}|-1)}$$ Increase probability on other topoi

An example

$\mathbb{T} = \{\tau_1, \tau_2\}, \alpha = 2$
$C_S(\tau_1) = 0, C_S(\tau_2) = .2;\ C_L(\tau_1) = .8, C_L(\tau_2) = .3$
$Pr(\tau_1) = .75, Pr(\tau_2) = .25$

	Accept		Reject	
τ_1	$1 - C_S(\tau_1) = 1$	$1 - C_L(\tau_1) = .2$	0	$C_L(\tau_1) = .8$
τ_2	$1 - C_S(\tau_2) = .8$	$1 - C_L(\tau_2) = .7$	0	$C_L(\tau_2) = .3$

$\text{Utility}_S(\tau_1) = Pr(\tau_1) - C_S(\tau_1) = .75$
$\text{Utility}_S(\tau_2) = Pr(\tau_2) - C_S(\tau_2) = .05$

S chooses τ_1 based on estimated utility, L rejects based on actual payoff.

Update: $Pr(\tau_1) = .75 - \frac{.75}{2} = .375, Pr(\tau_2) = .25 + \frac{.75}{2\times 1} = .625$
$\text{Utility}_S(\tau_1) = Pr(\tau_1) - C_S(\tau_1) = .375$
$\text{Utility}_S(\tau_2) = Pr(\tau_2) - C_S(\tau_2) = .425$

S chooses τ_2 based on new estimated utilities, L accepts based on actual payoff.

Do topoi have social meaning?

- We have suggested a way of choosing argumentational strategies based on social considerations
- The way linguistic cues are related to social meaning in sociolinguistics is by means of persona
- Can we relate personae to topoi?

Outline

Personae in terms of topoi

Returning to the balloon corpus...

Available topoi:

- τ_1: x is a child $\rightarrow$ don't sacrifice x
- τ_2: x may achieve great things $\rightarrow$ don't sacrifice x
- τ_3: There is a choice between sacrificing n people and $n+1$ people $\rightarrow$ sacrifice n people

Personae in terms of topoi

Returning to the balloon corpus...

Available topoi:

- τ_1: x is a child $\rightarrow$ don't sacrifice x
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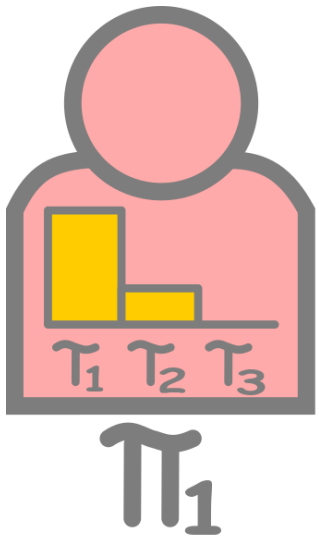
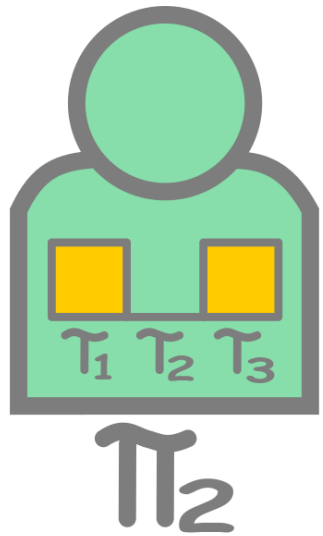
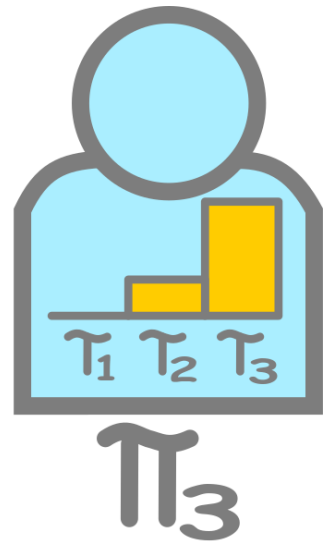
Relevant personae:



the virtue ethicist



the humanist



the cold rationalist

Outline

A probabilistic model of topoi as social signals

Some goals:

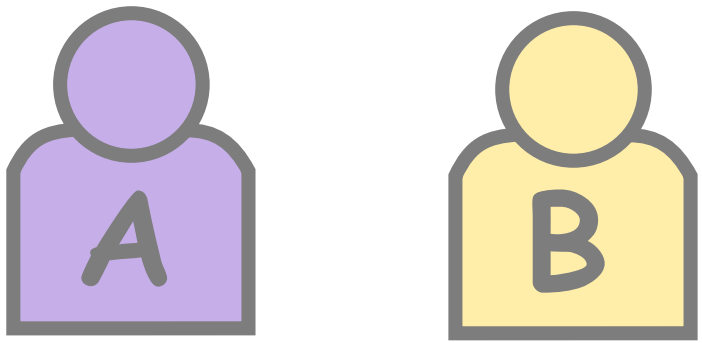
- Define the relationship between *topoi* and *personae*
- Formalize a notion of *social meaning* for topoi
- Model updates to the *social context* resulting from social signals, such as topoi.

A probabilistic model of topoi as social signals

Some goals:

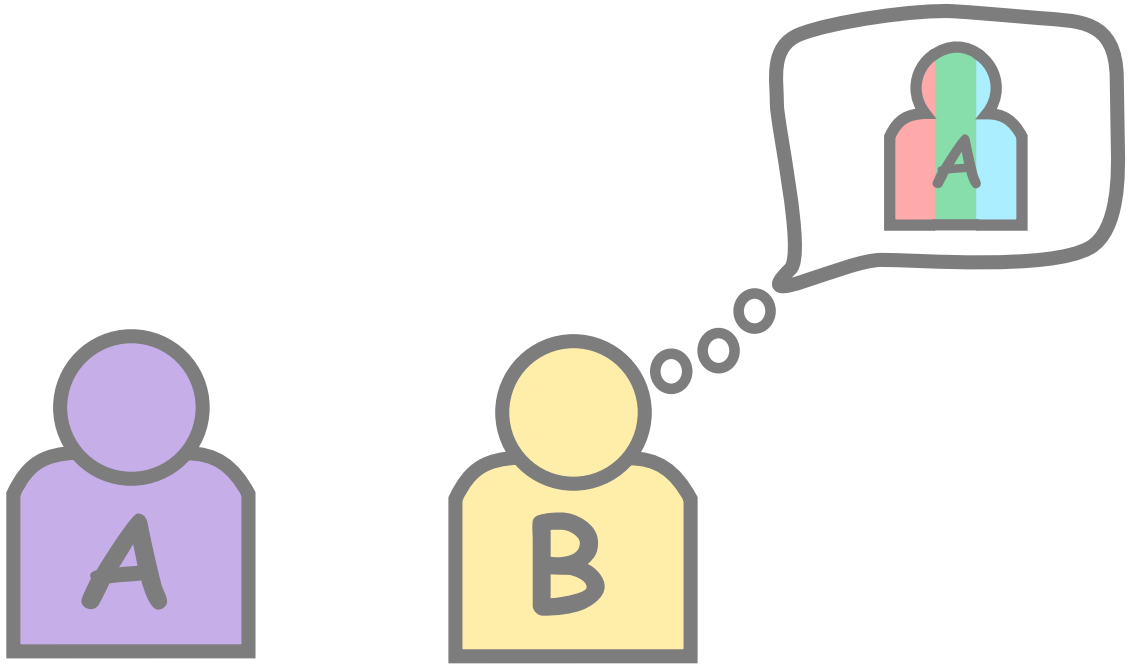
- Define the relationship between *topoi* and *personae*
- Formalize a notion of *social meaning* for topoi
- Model updates to the *social context* resulting from social signals, such as topoi.
- Lay the groundwork for *Bayesian social meaning games*
- Formulate some questions:
  - Do patients with schizophrenia use personae (via topoi) differently from non-patients?
  - How does social uncertainty contribute to the interpretation of social signals?

The setup...



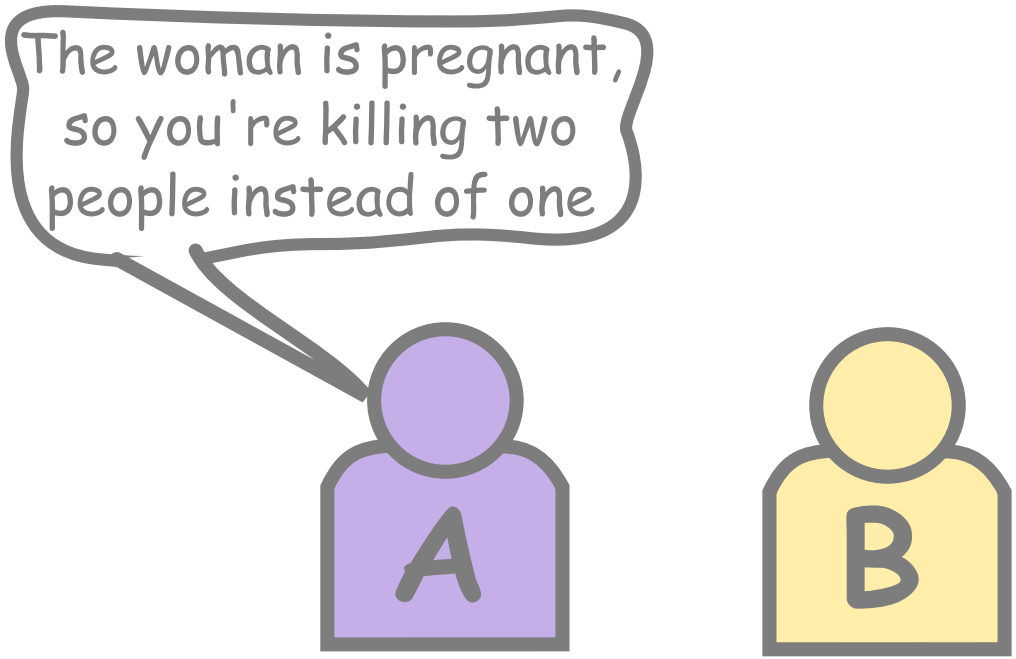
- Assume we have two speakers: A and B

The setup...



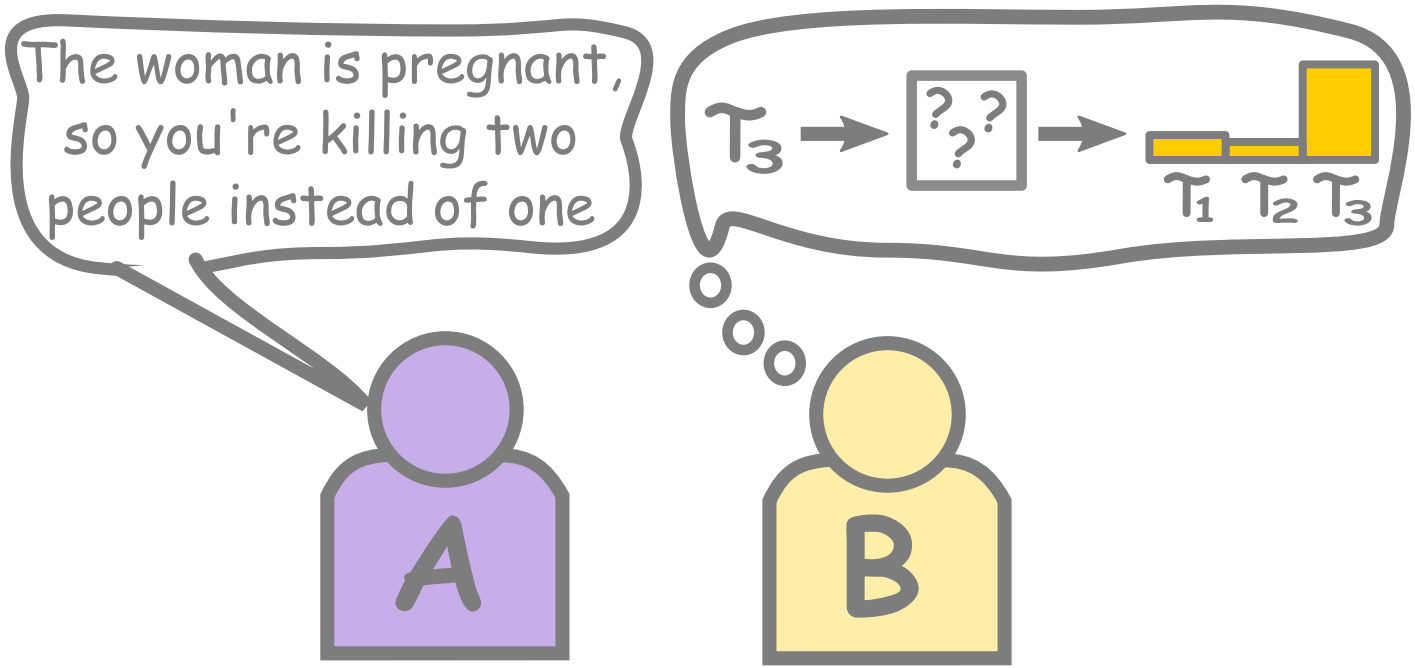
- Assume we have two speakers: A and B
- B's model of A is a probability distribution over personae, according to how likely B finds each as a persona for A

A wild utterance appears!



- Which topos does the utterance *evoke*?

A wild utterance appears!



- Which topos does the utterance *evoke*?
- What is the social meaning of that topos?
  - We define the social meaning of the topos in terms of *ideologically related* topoi.
  - This relatedness goes through the personae it projects.

Let's take a minute to justify this. . .

Social meaning as an indexical field

> *The the meanings of variables are not precise or fixed but rather constitute a field of potential meanings – an indexical field, or constellation of ideologically related meanings, any one of which can be activated in the situated use of the variable.*
>
> Eckert (2008)

- The social meaning of a topos is a probability distribution of idealogically related topoi:

$$[\![\tau^*]\!]_\Delta(\tau) = Pr(\tau \mid \tau^*)$$

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- The social meaning of a topos is a probability distribution of idealogically related topoi:

$$[\![\tau^*]\!]_\Delta(\tau) = Pr(\tau \mid \tau^*)$$

- *Idealogically related* means related **through personae**:

$$Pr(\tau \mid \tau^*) = \sum_{\pi \in \Pi} Pr(\tau \mid \pi) \cdot Pr(\pi \mid \tau^*)$$

The category adjustment effect

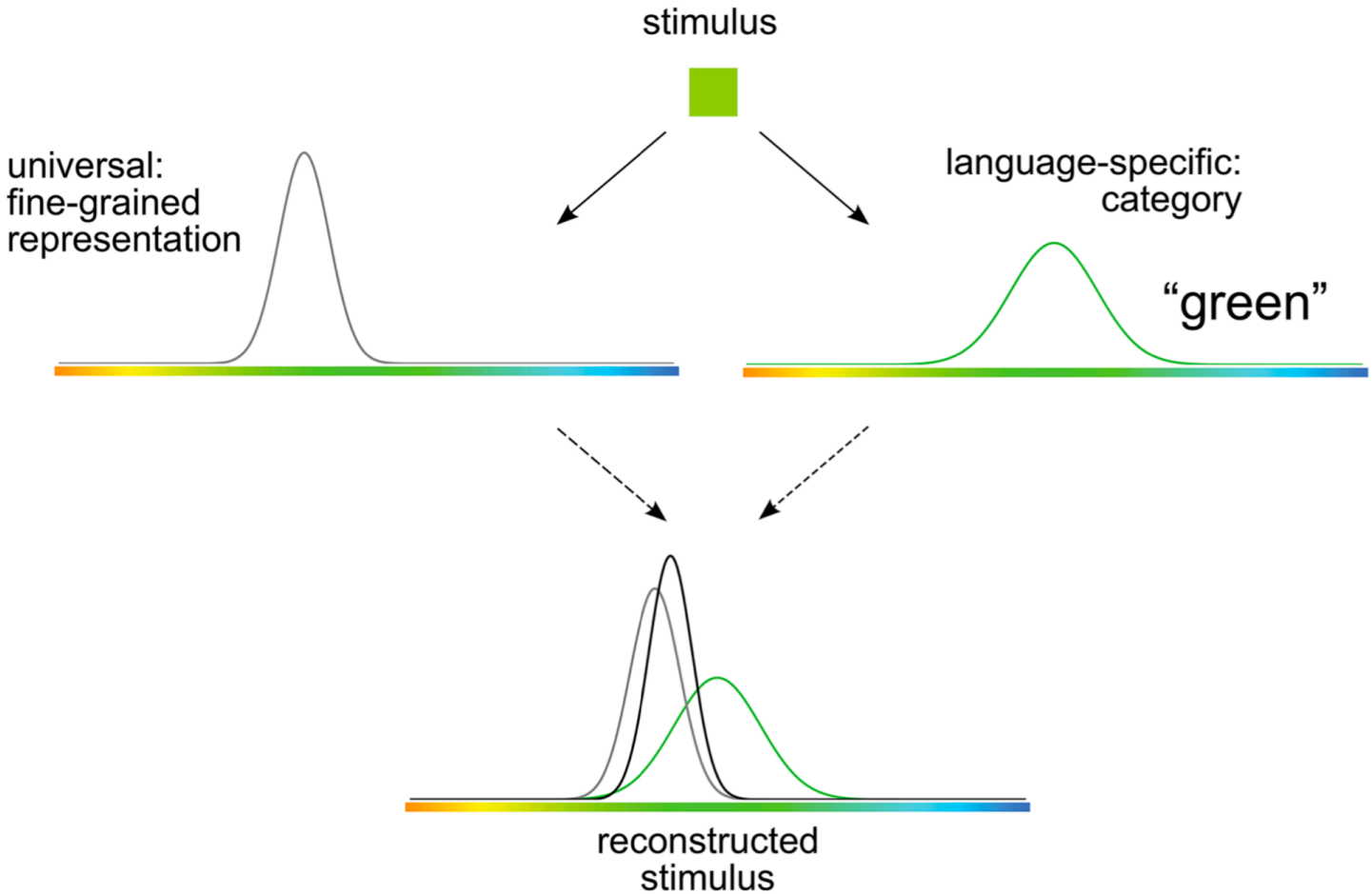


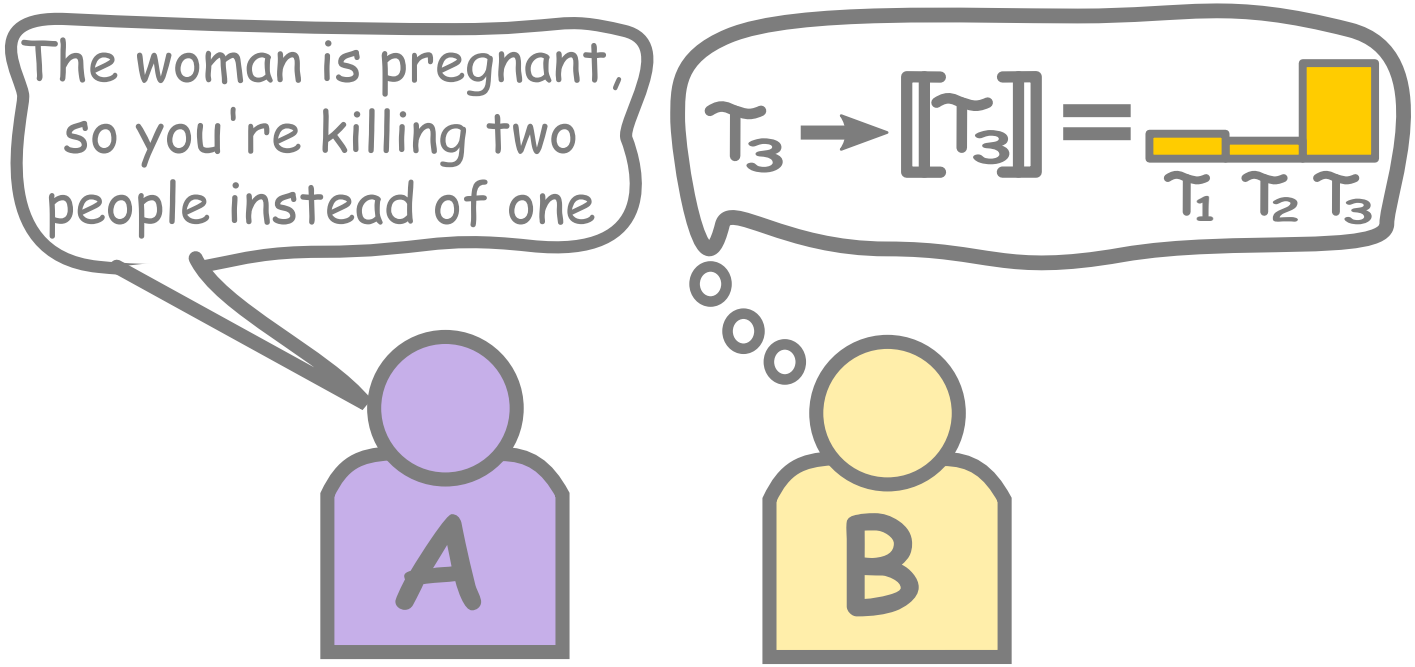
Figure: Figure 3 from Regier and Xu (2017)

The category adjustment effect

- Stimulus = The topos
- Category = Personae
- *Reconstructed stimulus* = A distribution over topoi (i.e., the indexical field)

$$
\begin{aligned}
[\![\tau^*]\!]_\Delta(\tau) &= Pr(\tau \mid \tau^*) \\
&= \sum_{\pi \in \Pi} Pr(\tau \mid \pi) \cdot Pr(\pi \mid \tau^*) \\
&= \sum_{\pi \in \Pi} Pr(\tau \mid \pi) \cdot \frac{Pr(\tau^* \mid \pi) \cdot Pr(\pi)}{Pr(\tau^*)}
\end{aligned}
$$

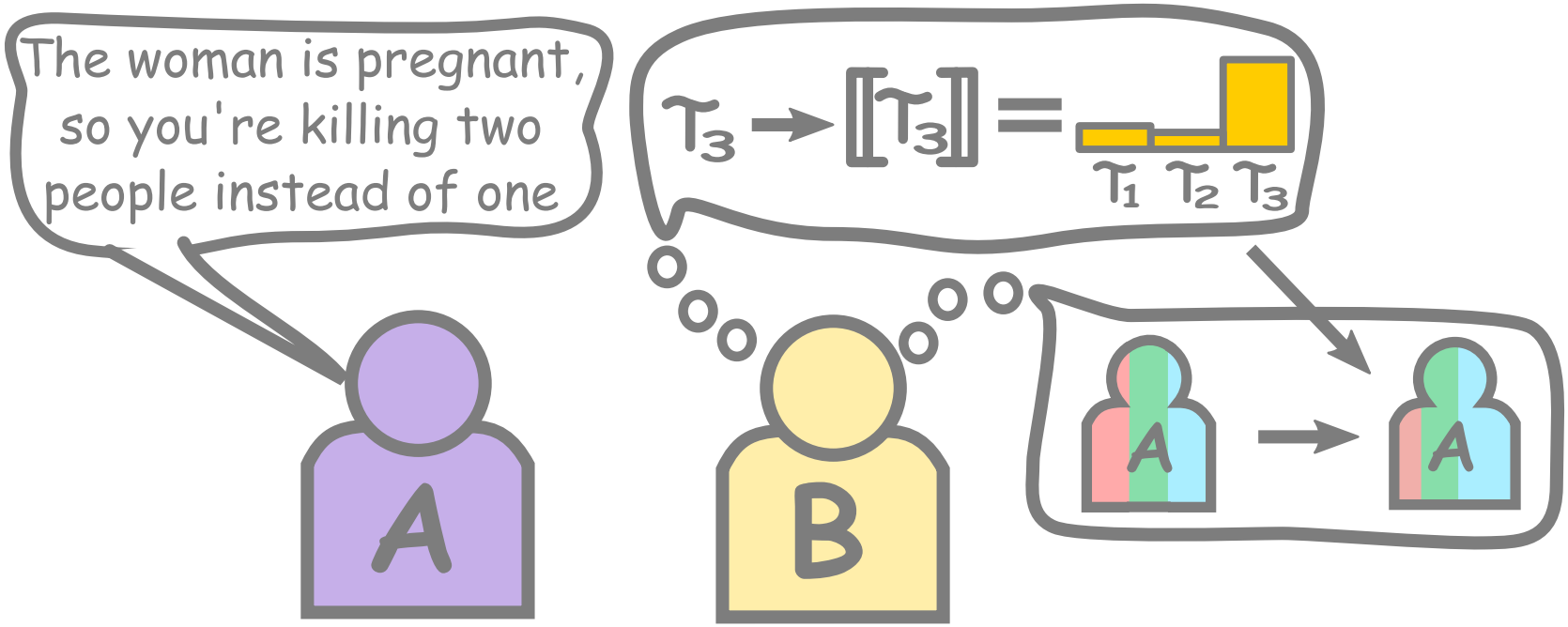
Once again: The social signal produced by τ_3



B interprets τ_3 as a distribution over other topoi it evokes:

$$[\![\tau^*]\!]_\Delta(\tau) = \sum_{\pi \in \Pi} Pr(\tau \mid \pi) \cdot \frac{Pr(\tau^* \mid \pi) \cdot Pr(\pi)}{Pr(\tau^*)}$$

Updating the social context



B updates her model of A's persona (as a result of A's use of τ_3):

$$\hat{Pr}(\pi) = \sum_{\tau} Pr(\pi \mid \tau) \cdot [\![\tau^*]\!]_{\Delta}(\tau)$$

Conclusions

- Games in TTR — no strategy for non-determinism
- Game theory — no integration into a general dialogue theory
- Combine the two kinds of game
- Games for choosing topoi
- Personae characterized in part by distributions over topoi

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