Human-computer dialogue

with *Game Theory …?*

Overview of the presentation ...

- An introduction to the domain — language
- Some theories of dialogue
- Towards a game-theoretic perspective

The domain: natural language

An outline of this section

Our goals here are to:

- Introduce some key terminology
- Hint at the complexities of the phenomenon
- Begin hinting at some potential applications for game theory

Some basic terminology

- *sentence* vs *utterance*
- the *descriptive* (*constative*) *fallacy*
- *propositional content* vs *pragmatic meaning*
  - *illocutionary force*
  - *perlocutionary force*

Truth-conditional semantics

Ex.: let *S* = ”Letizia de Ramolino was the mother of Napoleon.”

- How can we capture the propositional content *P* of *S*?
- Let *W = {all possible worlds}*, *B = {True, False}*
- Then let *P(S) = f : W -> B*

Truth-conditional semantics — Pt II

Ex.: let *S* = ”Letizia de Ramolino was the mother of Napoleon.”

- This leads to certain expectations
  - Universality
  - Compositionality (*and, or, because,* etc.)

Performative speech (Introduction)

Is every sentence true or false? Examples?

- “I am the mother of Napoleon.”

If a sentence is neither true or false, is it nonsense?

- “This sentence is false.”

Are there patterns here?

Performative speech — Pt II

Are there utterances such that:

1. They do not describe, constate, or report;
2. They are neither true nor false;
3. Their uttering is, or is a part of, the doing of an action which would not normally be described as “just” saying something; and
4. They are not nonsense?

Performative speech — Pt III

There are.

- “I christen this ship the HMS *Barham*.”
- “I [...] take thee [...] to be my wedded wife.”
- “I promise to be there tomorrow.”
- “I advise you not to come.”
- “I hereby declare this meeting adjourned.”

Performative speech — Pt III (example)

Ex.: “I christen this ship the HMS *Barham*,” *as uttered when smashing a bottle against the ship’s stem*

- Neither true nor false
  - … because they are not describing, or reporting, or (con)stating

Performative speech — Pt III (example)

Ex.: “I christen this ship the HMS *Barham*,” *as uttered when smashing a bottle against the ship’s stem*

- Does not describe, constate, report
  - Is not *reporting* what I would be said to be doing in so saying …
  - … nor anything I *did* do or *will do* in the future

Performative speech — Pt III (example)

Ex.: “I christen this ship the HMS *Barham*,” *as uttered when smashing a bottle against the ship’s stem*

- Does not describe, constate, report
  - Is not *reporting* what I would be said to be doing in so saying …
  - … nor anything I *did* do or *will do* in the future
- To name a ship is precisely to say “I christen this ship”

Ex.: “I christen this ship the HMS *Barham*,” *as uttered when smashing a bottle against the ship’s stem*

- Is not nonsense
  - Unless you’re an early 20th century positivist philosopher of language

Performative speech — Pt IV

- Speech acts
- Explicit and implicit
- A lot of theory here across several literatures
  - Origins with J. L. Austin (1940’s/50’s)
  - Contrast with previous positivist view (Russel et al.)
- These are also known in some communities as ...

Performative speech — Pt IV

- Speech acts
- Explicit and implicit
- A lot of theory here across several literatures
  - Origins with J. L. Austin (1940’s/50’s)
  - Contrast with previous positivist view (Russel et al.)
- These are also known in some communities as … **dialogue acts**

Performative speech — Pt V

- Performative utterances are neither true nor false
- But they can “fail”
  - We’ve mentioned they “go through” “under proper circumstances”
  - What are those circumstances?

Performative speech — Pt V

Felicity conditions

- (Misapplications)
  - Convention existence
  - Convention appropriateness
- (Misexecutions)
  - Incorrect execution
  - Incomplete execution
- (Abuses)
  - Insincerity
  - Infidelity

Performative speech — Pt VI

- So far, all our examples have been of the form “I *X*,” where X is the name of the action I perform (asking, naming, warning, betting, etc.)
- For example:
  - “I [hereby] request that you close the door.”
- But we don’t typically speak this way

Performative speech — Pt VI (continued)

Ex.: “I [hereby] request that you close the door.”

- “I want you to close the door.”
- “Can you close the door?”
- “Would you mind closing the door?”
- “Hadn’t you better close the door?”
- “Would you mind awfully if I were to ask you to close the door?”

Performative speech — Pt VI (continued)

Ex.: “I [hereby] request that you close the door.”

- “I am sorry to have to tell you to close the door.”
- “Did you forget the door?”
- “How about a bit less breeze in here?”
- “Now Johnny, what do big people do when they come in?”
- “Johnny, what am I going to say next?”
- “Johnny, what do I always tell you?”
- “Brr.”

Performative speech — Pt VII

- We have an ability to infer the intentions of others
  - We act cooperatively
  - And we assume cooperation
- Leads to apparent arbitrariness of the signal (vis-a-vis classical semantics)
- This intuition has been formalized as follows ...

Performative speech — Pt VII (continued)

- Gricean *non-natural meaning*, or *meaning-nn*
  - **S** *meant-nn* ***z*** by uttering **U** iff:
    i. **S** intended **U** to cause effect ***z*** in recipient **H**
    ii. **S** intended *(i)* to be achieved simply by **H** recognizing that intention *(i)*

Performative speech — Pt VII (continued)

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- *Speaker (utterer) meaning* **vs** *timeless (conventional) meaning*

Performative speech — Pt VIII

- There are schemes for annotating dialogue acts
  - TRAINS corpus annotations
  - DAMSL
  - ISO 24617-2 Standard (DiAML)
    - Communicative functions (inform, agree, answer, confirm, offer, accept-offer, decline-offer, etc.)
    - Dimensions (allo-feedback, time management, turn management)

Performative speech — Conclusion

- How these might lead to a natural game theoretic interpretation of dialogue?

Coming up: *reasoning from context*

There are other context-dependent, non-truth conditional, defeasible pragmatic inferences:

- Indexicality/deixis
- (Pragmatic) implicature
- (Pragmatic) presupposition
- (Conceptual) Metaphor
- Politeness

Deixis — Pt I (*introduction*)

- **Context** can play a **role** in interpretation of NL utterances
  - “What am I about to say, Johnny?”
  - Interpreted as <command, “close door”> in the appropriate context(s)
- This seems intuitive to those of us without theoretical biases
- But just how *large a **role*** does it play?

Deixis — Pt I (*example i*)

What happens when information is missing?

- You need to talk to Professor X. You find a note on his door saying:
  - “I’ll be back **in an hour**.”

Deixis — Pt I (*example ii*)

What happens when information is missing?

- You're in a senior staff meeting with Captain Janeway. The Kazon attack and the lights go out just as Commander Chakotay says:
  - "Listen, I'm not disagreeing with ***you***, but with ***you***, and not about ***this*** but about ***this***."

Deixis — Pt I (*example iii*)

What happens when information is missing?

- You find a bottle washed up on the beach; inside is a message which reads:
  - “Meet me **here** a week from **now** with a stick about **this** big.”

Deixis — Pt I (*example iv*)

What happens when information is missing?

- You turn on the TV just in time to hear an interviewee say to a TV journalist:
  - “But I fundamentally disagree with **that**.”

Deixis — Pt II (*background* cont'd)

- These underspecified, inherently ambiguous words and expressions are called **deictic**
- Deictic expressions (**indexicals**) like these posed problems for early truth-conditional semantics
  - Can all indexical expressions be reduced to a single one?
  - Can this final pragmatic residue be translated out into a context-free metalanguage?

Deixis — Pt II (*background* cont'd)

- Deictic expressions evaluated according to **context**, which consists in a set of **deictic coordinates**
  - Imagine a 4D space — 3 spatial dimensions plus time
  - Speaker at the center (**deictic centre**)
  - Now imagine concentric circles — discrete zones of spatial, temporal, social proximity
    - These circles shift constantly (inferred on the fly)
  - Now add dimensions for the **participant** and **social** roles, and one for the unfolding **discourse** itself

Deixis — Pt II (*background* cont'd)

- Now our **context** is a 7-dimensional space centered at the **speaker**
- When **speaker** and **addressee** switch participant-roles, the entire coordinate system shifts to be the **addressee**
  - The meanings of all deictic expressions shifts accordingly

Deixis — Pt II (*background* cont'd)

*(... now our **context** is a 7-dimensional space centered at the **speaker** ...)*

- The **speaker** can also elect to **project** the deictic centre to another participant (empathy)
- This is complicated (children struggle to master it)

Deixis — Pt II

Recall now the five **deictic axes**:

- Person (participant) deixis
- Place deixis
- Time deixis
- Discourse deixis
- Social deixis

Deixis — Pt II (**person** *example)*

Roles: **speaker**, **addressee**, **audience** (and many others)

- “**I** am Letizia de Ramolino.”
- “Do **you** know the Muffin Man?”
- “**Someone** is hangry, isn’t **he**?”
  - “Yes, **Samuel Barham** is speaking.”
  - “Can Billie have some ice-cream, **Daddy**?”

Deixis — Pt II (**time** *example)*

Distinguish: **times** and **time spans** wrt *coding time* (CT) and *receiving time* (RT)

- “I’ll see you **tomorrow**.”
- “The match is on **Thursday**.”
- “Don’t shoot ***now***, shoot ***now*** and ***now***.”

Deixis — Pt II (**place** *example)*

Distinguish: **proximity** (***proximal***, ***distal***), **location**

- “Place it **here**.”
- “Give **that** one to me, and I’ll give you **this** one.”
- ”He’s **coming**“ **vs** “I’m **coming**.”
- “When I’m in the office, you can **come** to see me.”
- “I **came** over several times to **visit** you, but you were never there.”

Deixis — Pt II (**discourse** *example)*

Distinguish: **token mentions**, **inferred propositions**, **inferred intentions** or **actions**, etc.

- “Rhinoceros.” — “What’s that? Spell **it**.”
- “*&^#!” — “Don’t say **that**, Johnny.”
- “I’ve never seen him before.” — “**That**’s a lie.”
- “I guess I’m just not that kind of person.” — “**That**’s very noble of you.”

Deixis — Pt II (**social** *example)*

Distinguish: *social*, *hierarchical*, *familial* **rank** or **position**

- “I disagree, **Your Honor**.”
- “Parl**ez-vous** français?”
  - [Japanese pronoun/verb/adjective system]
  - [The taboo vocabulary (Dyalŋuy) in Dyirbal]

Deixis — Pt III

- Are the conventional words and phrases we've been considering alone in being **deictic**?
  - i.e., their reference is inferred in a deictic coordinate system
- Perhaps **all** (or **most**) **of language** is in some sense deictic or **contextually dependent**

Deixis — Pt III (*continued*)

- Consider the sentence: “That [[points to man drinking Vulcan tea across the room]] is Lieutenant Tuvok.”
  - ***gestural deixis***

Deixis — Pt III (*continued*)

- How about: “**That** *man over there drinking Vulcan tea* is Lieutenant Tuvok.”
  - ***non-gestural deixis***

Deixis — Pt III (*continued*)

- How about: “**That** *man over there drinking Vulcan tea* is Lieutenant Tuvok.”
  - ***non-gestural deixis***

Deixis — Pt III (*continued*)

- How about: “**The** *man drinking Vulcan tea [over there]* is Lieutenant Tuvok.”
  - ***definite description***
- Still asking the addressee to search the contextual space for a referent
- No longer specifying **which deictic dimension** to search along
  - *the* is ambiguous between deictic axes

Deixis — Pt IV

- Interpretation of deictic expressions relies on a running discourse context
  - ***conversational context*** or ***common ground***
- Referents come “pre-loaded” …
  - Common-sense knowledge, acculturation, etc.
- … or are **grounded** during discourse
  - **salience**, **feedback** channels, etc.

Deixis — Conclusion (frames)

But NB: *the* can also refer to discourse referents that have not yet been grounded

- This (and other linguistic issues) has been explained by
  - **Frame semantics** (Fillmore, 1982 *multaque sequentia*)
- Lexemes are understood in relation to a **semantic frame**
  - E.g. “sell” -> [buyer, goods, money, seller, *the various relations between these*]

Deixis — Conclusion (frames)

- Suppose I wish to refer to a particular merchant (i.e., *the seller* or, say, *the book seller*)
  - “The [book] seller” clearly doesn’t refer in the **null context**
  - I could first say “I met a [book] seller yesterday”
    - -> “The [book] seller was crafty” now **refers**
  - But I could also simply say “I bought a book yesterday”
    - -> “The [book] seller was crafty” now **refers** equally well

Deixis — Conclusion (frames)

- Mention of one concept **evokes** or **activates** the entire containing frame
- Whole networks of discourse can be activated and grounded without explicit mention
  - They become **salient** in the discourse context
  - E.g., *the forks* from *the restaurant*
- This is **surprising** -> *natural language is **crazy hard***

Implicature — Pt I

- We've seen that by relying on
  - Context
  - The addressee's ability to infer intention

  we can be perceived as meaning **more** than what we actually say
- Can we say more about exactly *how* this works?

Implicature — Pt I (*examples*)

- A: “Can you tell me the time?”
- B: “Well, the milkman has come.”
  - A lot of inferences have to be made to construe B as a cooperative response to A

Implicature — Pt I (*examples*)

- *[and then]*
  - “The lone ranger jumped on his horse and rode into the sunset.”
  - “The capital of France is Paris and the capital of England is London.”
- *[and only]*
  - “The flag is white.”
  - “The flat is white, red, and blue.”
- … and many more
  - But how do they work?

Implicature — Pt II

- Gricean **maxims of conversation**
  - Inhere in the **cooperative principle**
  - *“Make your contribution such as is required, at the stage at which is occurs, by the accepted purpose or direction of the talk exchange in which you are engaged.”*

Implicature — Pt II

- Gricean **maxims of conversation**
  - The *maxim of Quality*
  - The *maxim of Quantity*
  - The *maxim of Relevance*
  - The *maxim of Manner*
- The **maxims** may be **observed** or **flouted** (**exploited**)

Implicature — Pt II

1. The **maxim of Quality**
    a. Try to make your contribution one that is true, specifically:
        i. Do not say what you believe to be false
        ii. Do not say that for which you lack adequate evidence

Implicature — Pt II

1. The **maxim of Quality**
2. The **maxim of Quantity**
    i. Make your contribution as informative as is required for the current purposes of the exchange
    ii. Do not make your contribution more informative than is required

Implicature — Pt II

1. The **maxim of Quality**
2. The **maxim of Quantity**
3. The **maxim of Relevance**

Make your contribution relevant

Implicature — Pt II

1. The **maxim of Quality**
2. The **maxim of Quantity**
3. The **maxim of Relevance**
4. The **maxim of Manner**
    a. Be perspicuous, and specifically:
        i. Avoid obscurity
        ii. Avoid ambiguity
        iii. Be brief
        iv. Be orderly

Implicature — Pt II

1. The **maxim of Quality**
2. The **maxim of Quantity**
3. The **maxim of Relevance**
4. The **maxim of Manner**

- This may seem a philosopher's utopia
- But Grice means we assume and exploit these subconsciously
  - This is how we manage inferences from "cooperativity"

Implicature — Pt III

- The **conversational implicatures** are the inferences we make by assuming the
  - **cooperative principle** and the
  - **maxims of conversation**
- This is not your grandmother's notion of "linguistic meaning" — this is "please guess what I'm thinking"

Implicature — Pt III

Recall now:

- **Illocutionary force** — *inferred communicative intention*
  - i.e., <**request** that **you pass me the salt**>
- **Perlocutionary force** — *inferred non-communicative intention*
  - i.e., <**physical effect** such that the salt ends up in front of me so that I can use it>
  - Typically enough to get addressee to infer perlocutionary intent

Metaphor — Pt I

- We got a metaphor to go through by exploiting the maxim of quality
- How often does this sort of thing happen in NL?
  - This question has given rise to an important field in cognitive linguistics:

conceptual metaphor theory

Metaphor — Pt II

- MORE IS **UP**; LESS IS **DOWN**
  - The number of books printed each year keeps going *up*. His draft number is *high*. My income *rose* last year. The amount of artistic activity has gone *down* in the past year. The number of errors he made was incredibly *low*. His income *fell* last year. He is *under*age. If you're too hot, turn the heat *down*. Temperatures are *plunging*. I got a *low* score on the test. ***Etc.***
- HAVING CONTROL OF FORCE IS **UP**; BEING SUBJECT TO CONTROL OF FORCE IS **DOWN**
  - I have control *over* her. I am *on top of* the situation. He's in a *superior* position. She's at the *height* of her power. He's in the *high* command. She's in the *upper* echelon. His power *rose*. He ranks *above* me in strength. I've got things *under* control. He *fell* from power. His power is on the *decline* (it's going *down*). He's my social *inferior* (he's *lower* than me socially). He is the *low* man on the totem pole. She's *high up* on the totem pole. ***Etc.***

Metaphor — Pt II (*continued*)

- Can you think of any others?
  - AN ARGUMENT IS A BUILDING
  - AN ARGUMENT IS A JOURNEY
  - AN ARGUMENT IS A CONTAINER
  - UNDERSTANDING IS SEEING
- These can combine and interact ...

Metaphor — Pt III

- Conceptual metaphor theory would claim that most language is metaphorical in this sense, grounded in …
- … embodied experience
  - The classic theory is due to Lakoff and Johnson

Metaphor — Conclusions

- Begs the question:
  - How much success will NLP have w/o access to general reasoners?
  - Is a simulation of the embodied condition necessary in order to process artificially the richness of NL?
- Of course, we're not the first to ask this …
  - (Nancy) Chang & (Benjamin) Bergen — **ECG**
    - Embodied Construction Grammar

Some initial conclusions

Before we proceed … (Pt I)

This stuff is hard

- Context-dependent
- Appears to rely on very general reasoning abilities
- Appears to interact in complicated ways with common sense knowledge

Before we proceed … (Pt II)

This stuff is important

- “Do you know how to get to the front desk?” — “Could you tell me how?” — “I need to know how.”
- “Do you know where John is?” — “I saw a yellow VW …”
- “Are you really going to eat all that?”
- “I went to a restaurant last night. The forks were dirty.”

Before we proceed ... (Conclusion)

We’re gonna be looking at *sequences* of this stuff

- Accumulative context
- Interactions between time indices

Our task is to try and come up with a **game-theoretic way** of analyzing it

First we should briefly review some classical theories ...

An introduction to human dialogue

The joint attention management model

- Cognitive psychological perspective
- Dialogue is joint attention management
- “Intending that others jointly attend” (Tomasello, 1998)
- The gist:
  - In a joint process of negotiation, agents build, maintain, and modify a set of discursive referents (a discourse context) and focus each other’s attention on them

Attentional model — Pt II

How does this help us?

Attentional model — Pt II

How does this help us?

All dialogue is:

- Joint (intersubjective)
- Negotiative (*i.e.*, recursive grounding and repair sequences)
- Collaborative
- Attentional
- Inferential (re: attention)

The *dialogue grammar* model

- Origins perhaps in 1971 paper by C. L. Hamblin
  - “Mathematical Models of Dialogue”
  - Misguided, to put it kindly
  - But productive ...
- Led to series of papers by (William) Mann, (Richard) Power, (Amy and Steven) Isard, (Jean) Carletta,
  - Some of this work refers to interactions in dialogue as conversational “games”

The *dialogue grammar* model

- In these models, dialogue construed as a path through an RTN
  - Transitions between states are “moves”
  - Moves amount to our dialogue acts
- Led to the more powerful Information State model
  - David Traum (USC)
- Dialogue systems written using these models tend to be …
  - Based on hand-written rules
  - Brittle
  - Highly domain-dependent

The sequence organization model

- Field of **Conversational Analysis**
  - Founded by Sachs, Schegloff, Jefferson
  - Originated in sociology, specifically ...
  - … ethnomethodology of (Harold) Garfinkel and (Erving) Goffman
- Study of how meaning unfolds over the course of social interaction
  - How a linguistic interaction is organized
  - How language users manage the interaction

The sequence organization model

- **Turn-taking** behavior
  - **TCU**, or **Turn-construction unit** (= utterance, roughly speaking)
  - **TRP**, or **Transition relevance place**
  - **Next speaker selection**
- **Adjacency pairs** (first pair part, second pair part)
  - Sequence **expansion**
  - Sequence **collapse**
- **Repair**

The contribution model

- Due to (Herbert) Clark and (Edward) Schaeffer
  - Cognitive linguistics and cognitive psychology
  - They also synthesize much early work in the **philosophy of language**, **pragmatics**, and **CA**
- **Contribution** (to **common ground**)
  - Joint action
  - **Presented** and **accepted** -> **grounded**
  - Once again, we have **cooperation**

Game Theory

(To the rescue ...?)

Recap: natural language is hard

Many natural tasks in NLP require *very* little “real” understanding of language:

- Word-sense disambiguation,
- Question answering,
- Document classification, *and even*
- Document summarization

Recap: natural language is hard

But *the buck stops with dialogue* —

- I.e., when you let people talk to a computer the way they really talk —
  - We assume a lot of “pre-loaded” common ground
    - Common-sense knowledge
    - Knowledge of social/linguistic conventions
  - We assume “cooperativity” in a technical, linguistic sense of the term

It’s possible game theory can help ...

- But we still need to figure out how
  - Dialogue systems research was abandoned for a decade
  - Lack of productive research on applying game theory
- Recent (i.e., few years) resurgence in dialogue systems research via …
  - Neural dialogue systems
  - Many encouraging initial results (Serban, Courville, Sordoni, Bengio, Pineau …)

Beginning with *neural* dialogue systems ...

- Nirat and I have attacked the problem from this angle
  - ANNs are, with some mild assumptions, *general* function approximators
  - Can model hierarchical time dependencies (context)
- But it is clear:
  - NDS are not an automatic panacea
  - It is still unclear how to model the *cooperative, contributional* nature of dialogue ...
  - ... or how to integrate common sense knowledge

Thoughts ...

- I do have some thoughts
- Before I proceed …
  - … do you have any thoughts about what game theory might have to say about NL dialogue?

Thoughts ...

- First approximation
  - **players** -> dialogue participants
  - **actions** -> dialogue (speech) acts
  - Cooperative game

Thoughts ...

- First (high-level) approximation
  - **players** -> dialogue participants
  - **actions** -> dialogue (speech) acts
  - Cooperative sequential imperfect information game
    - Strategies unfold over turns
    - We know ***U***, the utterance chosen
    - We are uncertain of ***A***, the dialogue act chosen

Thoughts … (*cont'd*)

- **Information set** -> distribution over ...
  - likely sequence of {***A***}n
  - *extra-linguistic goals of other player(s)?*
- **Utility function** -> relevance(***A*** | {***A***}n) (relevance of contribution ***A*** to the current likely dialogue state)
  - By analogy to the **principle of cooperation**, Player 2 knows Player 1 has chosen some ***An-1*** to maximize relevance(***An-1*** | {***A***}n-1)
    - We thereby update the information set
  - Choose the most relevant ***An*** in expectation given the information set

Thoughts … (*cont'd*)

- Enormous room for refinements …
  - Turn-based
    - In NL dialogue, turn-taking organization arises out of a real-time substrate via monitoring, feedback, inference
    - Real-time game? Differential game?
  - How to measure relevance?
    - Learn from data via ML?
    - Real-world NL data is noisy and mistake-ful

Thoughts … (*cont'd*)

- Not yet formal enough for implementation
  - May also still profitably *influence* or *guide* the design of an algorithm, architecture, or procedure ...

Some conclusions

For the sleepy

What we learned ...

- NL is hard
  - NL use is fundamentally cooperative
  - Meaning is inferred from common ground (context + shared assumptions + common sense), not given by words

What we learned … (*cont'd*)

- Dialogue is harder
  - Common ground (CG) accumulative
  - Contributions …
    - update CG
    - must be mutually accepted and known to be accepted

What we learned … (*cont'd*)

- Game theory may be able to help by providing a framework for modeling dialogue as …
  - A cooperative, dynamic game
  - Shared public objectives of *relevance*, *coherence*, *cooperativity*
  - Potentially disjoint private objectives
    - Individual linguistic goals goals (express an opinion)
    - Individual extra-linguistic goals (schedule an appt)