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ESSLLI2022 Advanced Course on Computational Models of Grounding in Dialogue

David Traum traum@ict.usc.edu

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What is Grounding?

- Not electrical grounding
- Not postponing space rocket flights
- Not crashing a ship onto land
- Not symbol-grounding
- Establishing common ground (Clark & Wilkes-Gibbs '86)

Establishing Common Ground

- What is common ground
- How is it established?
- What do we need it for?
- In what conversational domains have people studied it?
- How can we model it (& aspects of it) Conversationally?

Computational Models of Dialogue (Grounding)

Formal Models of Human interaction

- Automated recognition/classification
- Prediction

Generative/Participation models

- Human-computer (spoken) dialogue system
- Robot
- Virtual Human

Purposes for Artificial Agents



- Applications
 - As intelligent/natural social interface to Computers and Information (e.g. Alexa, Siri)
 - As virtual role-player (e.g. for training doctor-patient interviews, teamwork, cross-cultural negotiation,...)
 - For fun (open domain chatbots)
- Cognitive/Social Science Research
 - Stimulus for Social Interaction experiments (virtual confederate)
 - Reification of Pragmatics Theory

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Virtual humans:

What are they?

- Intelligent agents that support meaningful social interactions with human users in virtual reality
 - Play the role of teachers, peers, adversaries
- "Avatars" with a computer brain
 - Communicate through speech & gesture
 - Reason about environment
 - Understand and express emotion



What can they do?



- Portable, low-cost approach to supplement face-to-face interaction
- People respond "as if" they were human
 - Social facilitation (Hayes et al. 2010)
 - Impression management (Krämer et al. 2003)
 - Stereotype bias (Lok et al. 2008)
- Training control and consistency
 - Ensure consistency across trainees
 - Systematic manipulations
 - Incorporate "involuntary" behaviors
- Evaluate formal behavior models
 - Through perception studies
 - In context of interaction
 - Find gaps in interaction

Grounding Domains (1)

Problem Domain	Specific Task	Representative Studies
	Tangram matching task	Clark & Wilks Gibbs, 1986,
		Schober & Clark, 1989
		Yamashita et al., 2009
	Maptask	Stirling et al., 2000,
Matching		Mushin et al., 2003
		Rothwell et al., 2021
	Selection of a common object across multiple views	Udagawa and Aizawa, 2019, 2020, 2021,
		Rothwell et al., 2021
	Campus and map	Brennan 1990
	Auto direction giving	Novick & Sutton, 1994
Direction giving		Matheson et al., 2000
	Campus	Nakano et al., 2003
	Based on map information	Boye et al., 2014
	General	Clark & Schaefer, 1989
		Allwood et al., 1992
		McRoy & Hirst 1995
Casual conversation	Japanese Aged & Younger	Takeoka and Shimojima,
	Dyads	2002
	First contact conversation	Allwood & Cerrato, 2003
		Hee et al., 2017
	First and Second Language	Umata et al., 2019

Grounding Domains (2)

Problem Domain	Specific Task	Representative Studies	
Air-traffic Control		Novick & Ward, 1993	
	Trains-91	Traum, 1994	
	Trains-93	Traum & Heeman, 1996	
Collaborative Planning &	Meeting scheduling	Yaghoubzadeh et al., 2015	
Decision-making	Ranking tasks	Hee et al., 2017	
	Spot the difference	Rothwell et al., 2017, 2021	
	What to take on a trip	Umata et al., 2019	
Question-answering system		Cahn & Brennan, 1999	
	Physics	Baker et al., 1999	
Collaborative Learning	Math tutoring	Buckley & Wolska, 2008	
	Geology	Le Bail et al., 2021	
	Folktales	Le Bail et al., 2021	
Military Missions	Army Platoon Mission	Traum & Rickel, 2002	
	Rehearsal Training	Traum 2004	
	Forward observer call for artillery fire	Roque and Traum, 2008	
	Tactical Questioning/interviewing	Roque and Traum, 2009	
	Remotely-piloted aerial system	Bibyk et al., 2021	
	Combat search and rescue	Rothwell et al., 2021	
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Grounding Domains (3)

Problem Domain	Specific Task	Representative Studies
Small group discussions	Workplace, direction-giving	Carletta et al., 2002
	Toy naming, pet peeves	Novick & Gris, 2013
Multi-modal mystery solving		Dillenbourg and Traum, 2006
Therapy Conversation		Bavelas et al., 2014
Human-robot instruction	Naming objects	Chai et al., 2016
	Placing objects	Schlangen et al., 2016
		Marge & Rudnicky, 2015
	Navigation	Traum et al., 2020
		Kawano et al., 2021
	Cooking	Kontogiorgos et al., 2021
Siri Dialogue		Ho, 2020
Directory Inquiries		Larsson et al., 2020
Text adventure games		Benotti & Blackburn, 2021
Visual Dialogue		Benotti & Blackburn, 2021
Whatsapp chat with emojis		Apriliani & Muslim, 2021
CSCW systems		Homaeian et al., 2021

Outline of Course (covered today)



- Preliminaries: representation, agency, communication, definitions & uses for common ground
- Common Ground: How it is modeled and achieved
- Clark and Schaefer's Model of Grounding
- Feedback and Error-handling in Spoken Dialogue Systems
- Early Computational Models of Grounding

- Miscommunication: The Good, the Bad, and the Ugly
- Multi-functionality of Utterances
- Multi-modal Grounding
- Degrees of Grounding
- Multiparty, Multilingual & Multifloor Grounding
- Incremental Grounding
- Use of grounding for other phenomena

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PRELIMINARIES: REPRESENTATION, AGENCY & COMMUNICATION

Linguistic Communication





Logic & Reasoning: Representation



Orange(O1) ∃ x: Orange(x)

 $\neg \exists y: Orange-Juice(Y)$



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Logic & Reasoning





¬∃ x: Orange(x)Orange-Juice(O2)∃ y: Orange-Juice(y)

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Logic & Reasoning: Action



Make-OJ(O1,O2)



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Logic & Reasoning: Plan





- Operator: Make-OJ
- Pre-condition: Orange(O1)
- Action: Make-OJ(O1,O2)
- Effects:
 - Delete: Orange(O1)
 - Add: Orange-Juice(O2)

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Belief



Believe (M,Orange(O1))







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Rational Agency



Believe Orange(O1)

Desire (M, \exists y: Orange-Juice(y)) Intend(M, Make-OJ(O1,O2)) Perform(M, Make-OJ(O1,O2) Orange-Juice(O2)





Rational Agency





Same Belief

.....





Individual And Joint Attitudes

Individual Attitudes

- Belief
- Desire
- Plan
- Intention

Multiparty (asymmetric) Attitudes

- Social Commitment
- Obligation

- **Joint Attitudes**
 - Mutual Belief
 - Joint Intention
 - Shared Plan

Communication





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COMMON GROUND: HOW IS IT MODELED AND ACHIEVED?

Common Ground needed for



- Concepts (objects, actions, plans,...)
- Sound -> language Phoneme
- Phonology
- Morphology
- Concept -> word
- Syntax
- Semantics
- Pragmatics

- Coordination
- Convention
 - Which side of the street to drive on?
 - "Dagen H"

5am on Sunday, 3 September 1967



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Models of Common Ground (MK, MB,...)

Primitive Attitude

Mutual Belief





Models of Common Ground (MK, MB,...)

- Iterated (Schiffer 72)
 - $K_s p \wedge K_A p \wedge K_s K_A p \wedge K_A K_s p \wedge K_s K_A K_s p \wedge \dots$

2nd level Iterated Belief







Models of Common Ground (MK, MB,...)

One-sided (e.g., Cohen '78 BMB)



Models of Common Ground (MK, MB,...)

- Fixed Point (Harman 77): "A group of people have mutual knowledge of *p* if each knows *p* and we know this, where this refers to the whole fact known"
- Shared Situation (Lewis 69): Let us say that it is *common knowledge* in a population P that X if and only if some state of affairs A holds such that:
 - 1. Everyone in **P** has reason to believe that **A** holds.
 - 2. A indicates to everyone in P that everyone in P has reason to believe that A holds.
 - 3. A indicates to everyone in **P** that **X**.

Mutual Belief





Models of Common Ground (MK, MB,...)

- Primitive Attitude
- Iterated (Schiffer 72)
 - $K_{s}p \wedge K_{A}p \wedge K_{s} K_{A}p \wedge K_{A} K_{s}p \wedge K_{s} K_{A} K_{s}p \wedge \dots$
- One-sided (e.g., Cohen '78 BMB)
- Fixed Point (Harman 77): "A group of people have mutual knowledge of *p* if each knows *p* and we know this, where this refers to the whole fact known"
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Iterated: proof of individual attitudes

- Truncation heuristics
- Circular pointer in deepest beliefs (Cohen 78)

Iterated: proof of individual attitudes

Truncation heuristics – Clark and Marshall '81

VERSION 1: On Wednesday morning Ann reads the early edition of the newspaper which says that *Monkey Business* is playing that night. Later she sees Bob and asks, *Have you ever seen the movie* showing at the Roxy tonight?

VERSION 2: On Wednesday morning Ann and Bob read the early edition of the newspaper and discuss the fact that it says that A Day at the Races is showing that night at the Roxy. Later, after Bob has left, Ann gets the late edition, which prints a correction, which is that it is Monkey Business that is actually showing that night. Later, Ann sees Bob and asks, Have you ever seen the movie showing at the Roxy tonight? K(A,P1)

K(A,P1) K(A,K(B,P2))

P1 = Monkey Business is playing at Roxy tonight P2 = A day at the races is playing at Roxy tonight

How is Common Ground **Achieved/Assumed?** Iterated: proof of individual attitudes

Truncation heuristics – Clark and Marshall '81

VERSION 3: On Wednesday morning Ann and Bob read the early edition of the newspaper, and they discuss the fact that it says that A Day at the Races is showing that night at the Roxy. When the late edition arrives, Bob reads the movie section, notes that the film has been corrected to Monkey Business, and circles it with his red pen. Later, Ann picks up the late edition, notes the correction and recognizes Bob's circle around it. She also realizes that Bob has no way of knowing that she has seen the late edition. Later that day Ann sees Bob and asks, Have you ever seen the movie showing at the Roxy tonight?

VERSION 4: On Wednesday morning Ann and Bob read the early edition of the newspaper and discuss the fact that it says that A K(A,K(B,K(A,K(B, P2)))) sees the late edition, notes that the movie has been corrected to Monkey Business, and marks it with her blue pencil. Still later, as Ann watches without Bob knowing it, he picks up the late edition and sees Ann's pencil mark. That afternoon, Ann sees Bob and asks, *Have you ever seen the movie showing at the Roxy* tonight?

K(A,K(B,K(A, P2)))

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Iterated: proof of individual attitudes

Truncation heuristics – Clark and Marshall '81

VERSION 5: On Wednesday morning Ann and Bob read the early edition of the newspaper and discuss the fact that it says that A Day at the Races is playing that night at the Roxy. Later, Bob sees the late edition, notices the correction of the movie to Monkey Business, and circles it with his red pen. Later, Ann picks up the newspaper, sees the correction, and recognizes Bob's red pen mark. Bob happens to see her notice the correction and his red pen mark. In the mirror Ann sees Bob watch all this, but realizes that Bob hasn't seen that she has noticed him. Later that day, Ann sees Bob and asks, Have you ever seen the movie showing at the Roxy tonight?

K(A, K(B, K(A, K(B, K(A, P2)))))

Iterated: proof of individual attitudes

- Truncation heuristics
 - Example: Vizzini in Princess Bride:



Shared Situation (Clark & Marshall)

- Observation of situation. Assumptions of sharedness

Basis for mutual knowledge		Auxiliary assumptions	
1.	Community membership	Community co-membership, universality	
		of knowledge	
2.	Physical copresence		
	a. Immediate	Simultaneity, attention, rationality	
	b. Potential	Simultaneity, attention, rationality, locatability	
	c. Prior	Simultaneity, attention, rationality, recallability	
3.	Linguistic copresence		
	a. Potential	Simultaneity, attention, rationality, locatability, understandability	
	b. Prior	Simultaneity, attention, rationality, recallability understandability	
4.	Indirect copresence		
	a. Physical	Simultaneity, attention, rationality	
		(locatability or recallability), associativity	
	b. Linguistic	Simultaneity, attention, rationality,	
		(locatability or recallability), associativity	
		understandability	

Table 2.1: Clark & Marshall's Methods of Achieving Copresence for Mutual Knowledge

Communication





Miscommunication





Grounding

- Feedback process

Clark & Schaefer's contribution model

Contributions to dialogue are collaborative achievements composed of two phases:

- Presentation Phase: A presents utterance u for B to consider. He does so on the assumption that, if B gives evidence e or stronger, he can believe that B understands what A means by u
- Acceptance Phase: B accepts utterance u by giving evidence e' that he believes he understands what A means by u. He does so on the assumption that, once A registers evidence e', he will also believe that B understands.

Communication





Iterated: proof of individual attitudes

- Truncation heuristics
- Circular pointer in deepest beliefs (Cohen 78)

Shared Situation

- Observation of situation
- Assumptions of sharedness (Clark & Marshall 81)

Grounding

- Feedback process (Clark & Schaefer 89)

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CLARK & SCHAEFER'S CONTRIBUTION MODEL OF GROUNDING

Clark & Schaefer's contribution model

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Serial Contribution Graphs



- A. how far is it from Huddersfield to Coventry.
- B. um. about um a hundred miles -
- A. so, in fact, if you were . living in London [etc]

Contribution Model

Each signal is also a presentation to be grounded

- Recursive model

•Grounding Criterion: ``The contributor and the partners mutually believe that the partners have understood what the contributor meant to a criterion sufficient for the current purpose''

-Graded Evidence:	1	Display	B displays verbatim all or part of A's presentation.
	2	Demonstration	B demonstrates all or part of what he has understood A to mean.
	3	${f Acknowledgement}$	B nods or says "uh huh", "yeah", or the like.
	4	Initiation of relevant next contribution	B starts in on the next contribution that would be relevant at a level as high as the current one.
51	5	Continued attention	B shows that he is continuing to attend and therefore remains satisfied with A's presentation.

Example of Contribution model – embedded repair request

$$C = \Pr - (1) \text{ A: is term OK - -}$$

$$Ac = \Pr - (2) \text{ B: what}$$

$$C = \Pr - (3) \text{ A: is term all right}$$

$$C = \Pr - (4) \text{ B: yes it seems all right so far, touch wood}$$

Contributions with embedded repairs



Contribution with installments



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Deficiencies of Contribution Model

Off-line model

- No way to tell recursion has finished until after the fact
- No clear specification of moves (for interpretation & generation)
- Not predictive of next utterances
- Issues with types of evidence

Types of Evidence

- Display: B repeats A's presentation verbatim
 Strongest?
- Demonstration: B demonstrates what he has understood
- Acknowledgement: B makes some sign that he has understood
- Initiate Next Contribution: B makes a relevant contribution
 Oblivious?
- Continued Attention: B shows he is satisfied with A's presentation

Grounding Gone Wrong



But "Hu" really is on first!

