ESSLLI2015 Advanced Course on Computational Models of Grounding in Dialogue

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Outline of Course (covered today)

- Preliminaries: representation, agency, communication
- Common Ground: How it is modeled and achieved
- Clark & Schaefer's Model of Grounding
- Computational Models of Grounding I: Brennan & Cahn
- Speech Acts and Dialogue Acts
- Multi-functionality of Utterances
- Feedback and Error-handling in Spoken Dialogue Systems
- Computational Models of Grounding II: Traum '94
- Miscommunication: The Good, the Bad, and the Ugly
- Decision-theoretic models of grounding
- Multi-modal Grounding
- Multiparty Grounding
- Degrees of Grounding
- Incremental Grounding

REVIEW OF YESTERDAY

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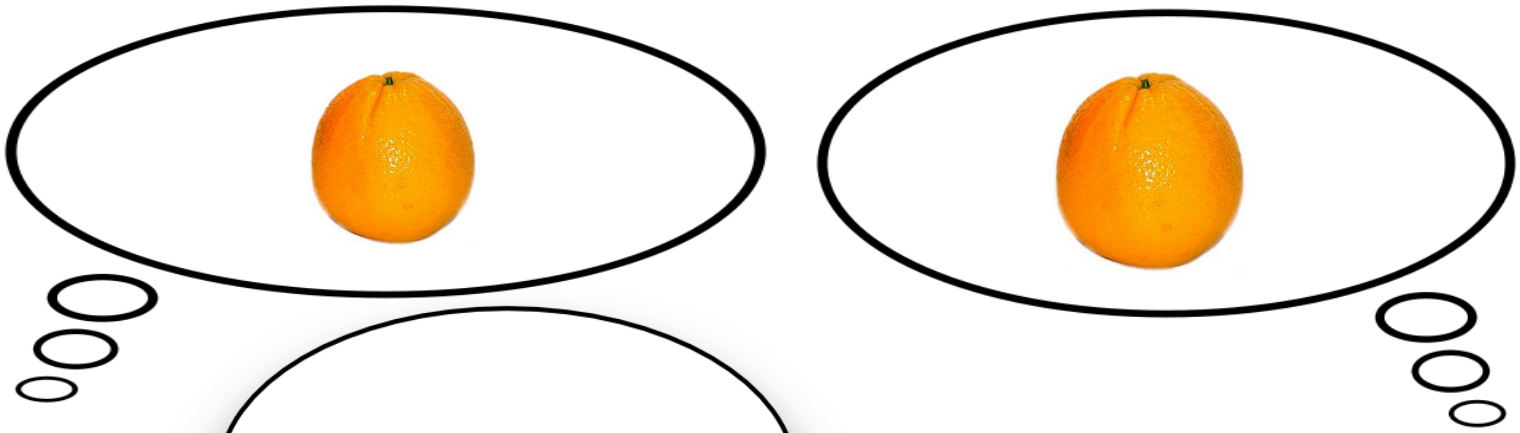
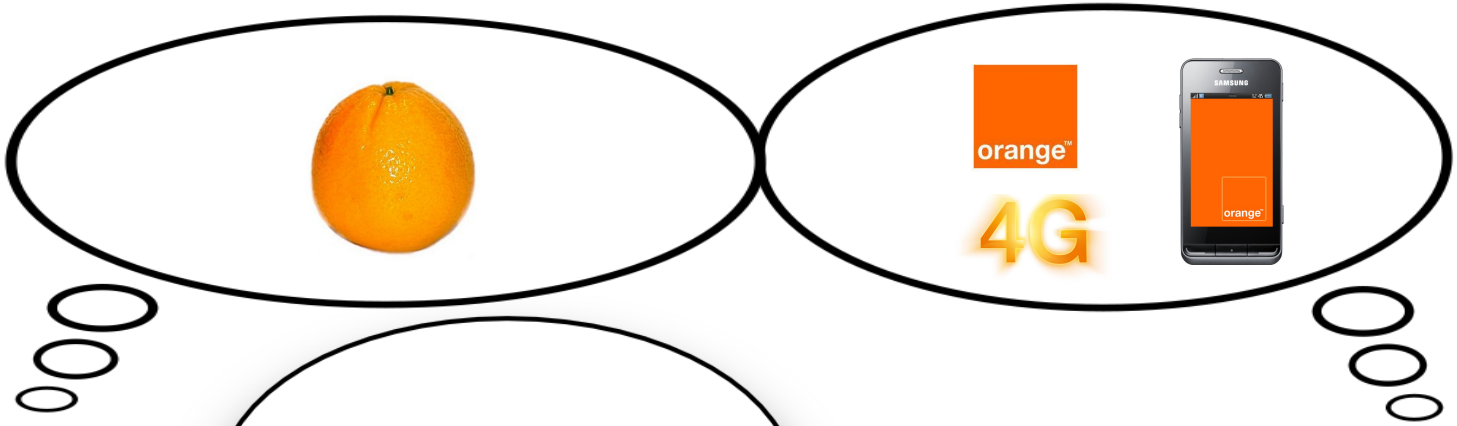
Communication



An orange

Miscommunication



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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

Models of Common Ground (MK, MB,…)

- **Primitive Attitude**
- **Iterated (Schiffer 72)**
  - $K_s p \wedge K_A p \wedge K_s K_A p \wedge K_A K_s p \wedge K_s K_A K_s p \wedge \ldots$
- **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"**
- **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.

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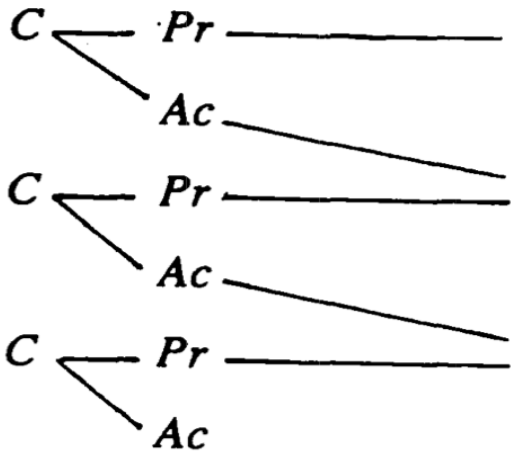
How is Common Ground Achieved/Assumed?

- **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)

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.

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]

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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	**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.
5	**Continued attention**	B shows that he is continuing to attend and therefore remains satisfied with A's presentation.

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**

COMPUTATIONAL MODELS OF GROUNDING I: BRENNAN AND CAHN 99

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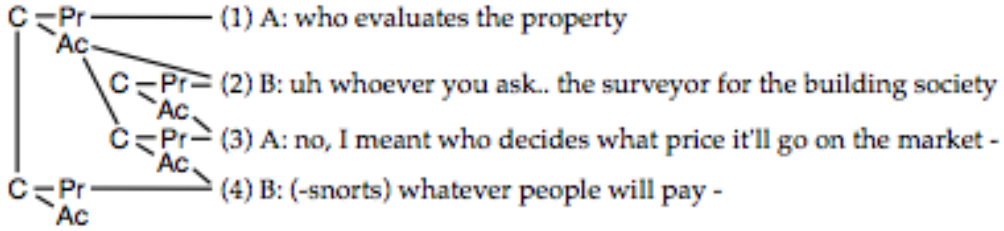
Brennan & Cahn 1999: Extensions to Clark and Schaefer

1. **All contribution graphs are private models from an individual's point of view**
   - C&S graph seen as composite final product
   - Incrementally constructed, utterance by utterance
2. **Task-specific heuristics for assessing evidence of understanding and grounding criterion**
3. **Principles for embedding contributions: only when not meeting grounding criterion**
4. **Addition of "Exchange" structure: propose and execute**
   - Remove unrooted medial contributions

Brennan & Cahn 1999:

- **Making contribution model more computational**
  - Multiple graphs from different points of view
  - Complex update operations
  - C&S:



  - B&C:

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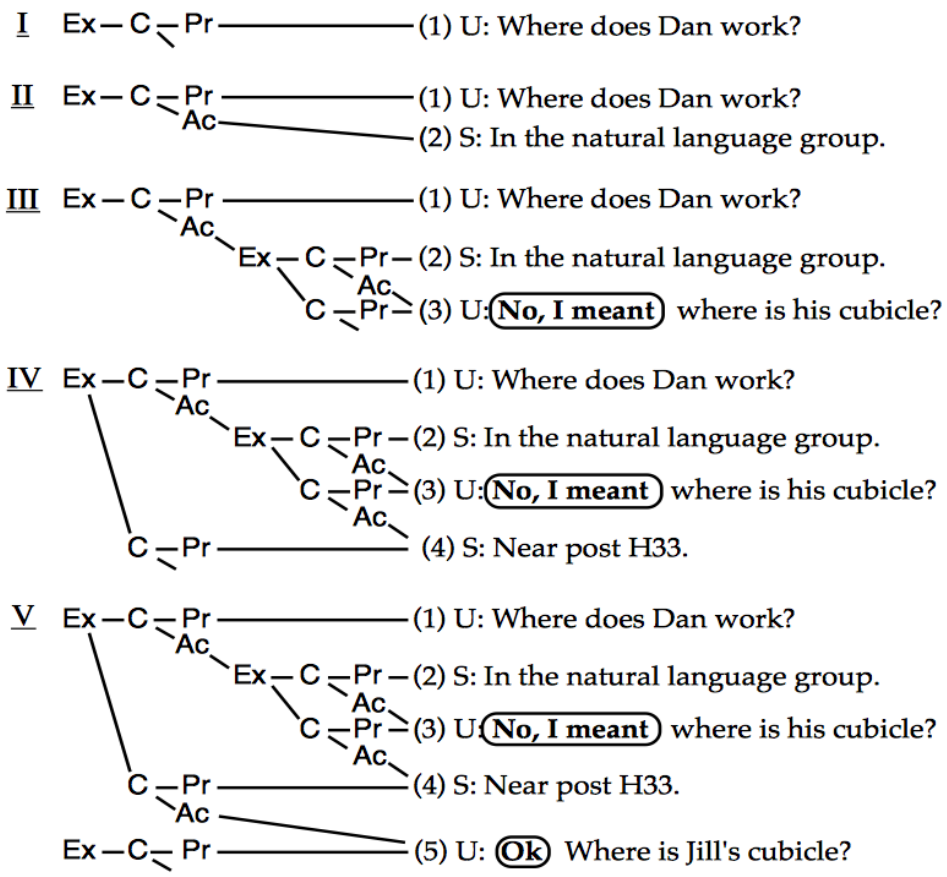
Brenan and Cahn: Use for dialogue with database application



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SPEECH ACTS AND DIALOGUE ACTS

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Speech Acts (Austin)

- **How to "Do things" with words**
  - Look at actions & effects of utterances rather than truth-conditions
  - Types of acts
    - Locutionary
    - Illocutionary
    - Perlocutionary

Searle's Speech Act Taxonomy

- Representatives
- Directives
- Commissives
- Expressives
- Declarations

Issues for Computational Theory of Speech Acts

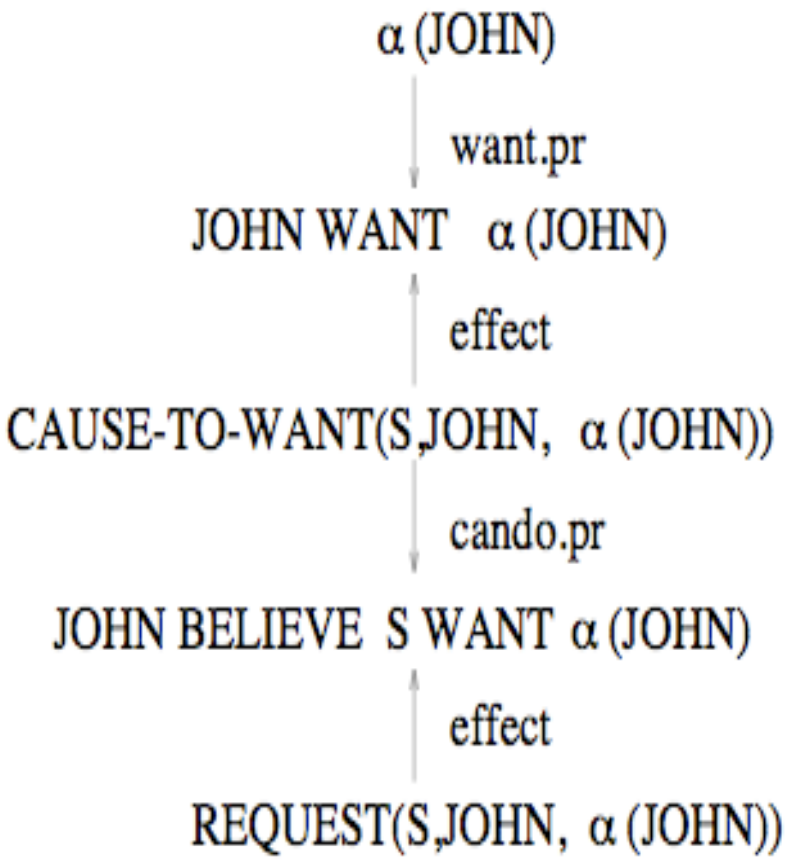
- **When can an act be recognized**
  - as sincere and successful?
- **What are the effects of performance of an act**
  - On state of hearer and speaker
  - On state of dialogue
- **When should act be performed?**
- **How should act be performed?**

Perrault, Cohen, Allen: Speech acts as Plan Operators

- **Preconditions & Effects (mental states)**
- **Decomposition (indirect speech acts)**
- **Planning and Plan Recognition for Speech acts**

Examples: Plans and Operators for Request

- Perrault & Cohen '79



- Allen '83

REQUEST(speaker,hearer,act)

Body: MB(hearer,speaker, speaker WANT hearer DO act)

Effect: hearer WANT hearer DO act

Dialogue Acts – Beyond standard Illocutionary acts

- Sinclair & Coulthard
- Bunt: Dialogue Acts
- Novick: Meta-locutionary acts
- Traum & Hinkelman: Conversation Acts

- Cover multiple dialogue phenomena
- Turn-taking
- Reference
- Grounding
- Discourse relations/ Adjacnecy pairs
- feedback

Levels of Dialogue acts: Traum & Hinkelman 1992

Discourse Level	Act Type	Sample Acts
Sub UU	**Turn-taking**	take-turn, keep-turn, release-turn, assign-turn
UU	**Grounding**	Initiate, Continue, Ack, Repair, ReqRepair, ReqAck, Cancel
DU	**Core Speech Acts**	Inform, YNQ, Check, Eval Suggest, Request, Accept, Reject,
Multiple DUs	**Argumentation**	Elaborate, Summarize, Clarify Q&A Convince Find-Plan

MULTIFUNCTIONALITY OF UTTERANCES

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Multifunctionality

A: Henry, could you take us through these slides?

H: O..w..k..ay.. just ordering my notes

Multifunctionality

A: Henry, could you take us through these slides?

Turn Assign **to Henry; *Request***

H: O..w..k..ay.. just ordering my notes

Multifunctionality

A: Henry, could you take us through these slides?

Turn Assign* to Henry; *Request

H: O..w..k..ay.. just ordering my notes

Turn Accept; Stalling; Accept Request; Inform

Multifunctionality

A: Henry, could you take us through these slides?

Turn Assign* to Henry; *Request

H: O..w..k..ay.. just ordering my notes

Turn Accept; Stalling; Accept Request; Inform

Dimensions of communication in dialogue:

- Turn Management
- Time Management
- Task performance
- .....

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Types of Feedback (Allwood et al 92)

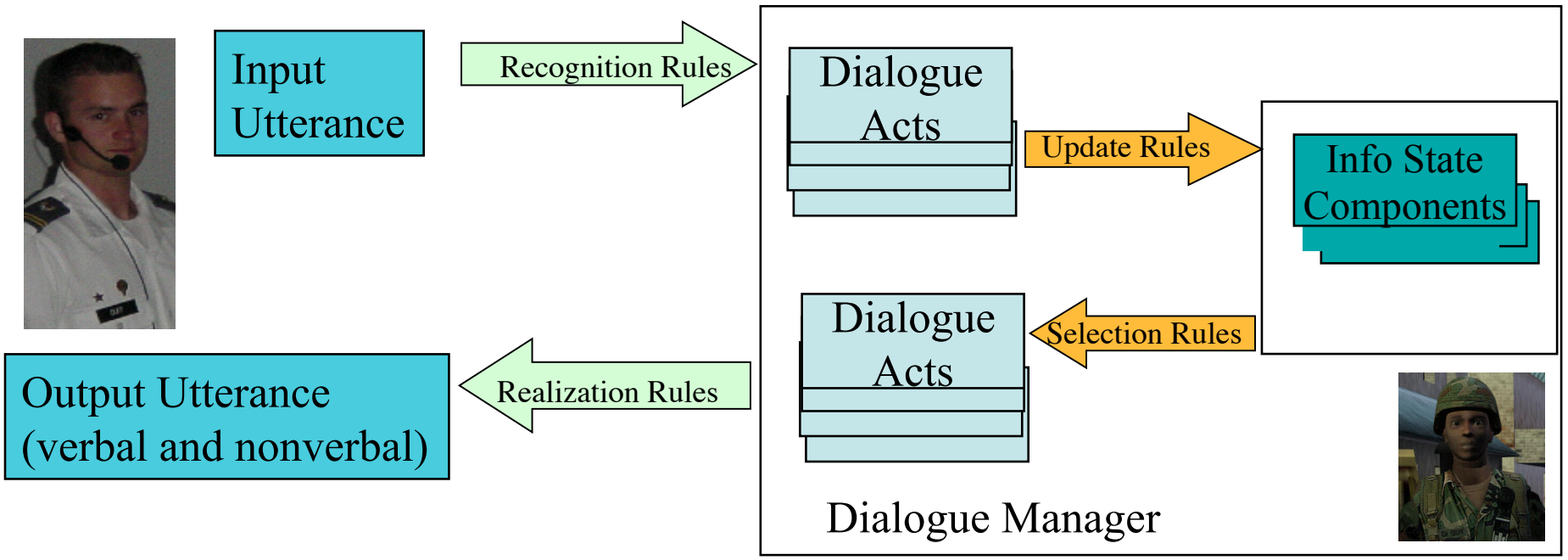
- **Levels:**
  - Contact
  - Perception
  - Understanding
  - Attitudinal Reaction
- **Signals types**
  - Request feedback
  - Prepare other
  - Provide
    - Positive
    - negative

Clark's levels of coordinated action

Level	Speaker *S*	Listener *L*
Conversation	S is proposing activity α	L is considering proposal α
Intention	S is signaling that p	L is recognizing that p
Signal	S is presenting signal σ	L is identifying signal σ
Channel	S is executing behavior β	L is attending to behavior β

Dialogue Approach: Layered Information State

- **Layer captures coherent aspect of communicative interaction (e.g., turn, grounding, obligations)**
- **Layer consists of**
  - Information State components (state of interaction)
  - Dialogue Acts (Packages of changes to information state)



Information State Model (Traum & Rickel 2002)

Layer	Info State Components	Dialogue Acts
Contact	Participant contact	Make-contact, break-contact
attention	Participant focus	Show, request, accept
conversation	Conversation, topic, participants	Start-conversation, end-conversation, confirm-start, deny-start, identify-topic, join, leave
Turn-taking	Conversation turn	Take-turn, keep-turn, hold-turn, release-turn, assign-turn
initiative	Conversation initiative	Take-initiative, release-initiative
grounding	Conversation CGUs	Initiate, continue, acknowledge repair, cancel, request-repair
Core	Social State (obligations, commitments, trust) Conversation QUD, Negotiation, CGU contents	Forward: assert, info-req, order, request, thank, greeting, closing, express, check, suggest, promise, offer, apology, encourage, accuse, intro-topic, avoid
		Backward: accept, reject, address, answer, divert, counterpropose, hold, check, clarify-parameter, redirect

Dimensions in dialogue act analysis

Criteria for distinguishing dimensions:

each core dimension should

- correspond to observed forms of communicative behaviour (be empirically justified)
- correspond to a well-established class of communicative activities (be theoretically justified)
- be recognizable with acceptable precision by humans and machines
- be addressable independent of other dimensions (be 'orthogonal' to other dimensions)
- be commonly represented in existing dialogue act annotation schemes

(Petukhova & Bunt, 2009)

Core dimensions

- **Task:** dialogue acts moving the underlying task forward
- **Auto-Feedback**: providing information about speaker's processing of previous utterances
- **Allo-Feedback**: providing or eliciting information about addressee's processing of previous utterances
- **Turn Management**: allocation of speaker role
- **Time Management**: managing use of time
- **Own Communication Management**: editing one's own speech
- **Partner Communication Management**: editing addressee's speech
- **Social Obligations Management**: dealing with social conventions (greeting, thanking, apologizing,..)
- **Discourse Structuring**: explicitly structuring the dialogue

Core communicative functions

Criteria for distinguishing communicative functions:

each communicative function should

- correspond to observed forms of communicative behaviour (be empirically justified)
- have a well-established semantics in terms of information-state updates (be theoretically justified)
- be recognizable with acceptable precision by humans and machines
- be included if necessary for achieving a good coverage of the phenomena in a given dimension
- be commonly present in existing dialogue act annotation schemes
- preferably be either mutually exclusive with the other functions available in a given dimension, or be a specialization of one

Core communicative functions

Dimension-specific communicative functions, e.g.:

- *Turn Release* (Turn Management)
- *Stalling* (Time Management)
- *Self-Correction* (Own Communication Management)
- *Completion* (Partner Communication Management)
- *Dialogue opening* (Discourse Structuring)
- *Thanking* (Social Obligations Management)

General-purpose functions, applicable in any dimension, e.g.:

- Information-seeking functions: *Propositional Question, Set Question, Check Question, Choice Question*
- Information-providing functions: *Inform, Agreement, Disagreement, Correction*
- Commissive functions: *Promise, Offer, Accept Suggestion, Decline Suggestion,...*
- Directive functions: *Request, Instruct, Suggestion, Accept Offer, Decline Offer*

FEEDBACK AND ERROR HANDLING IN SPOKEN DIALOGUE SYSTEMS

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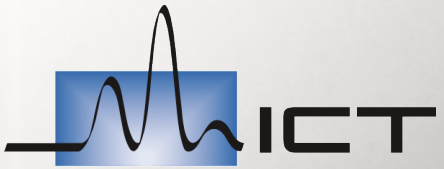

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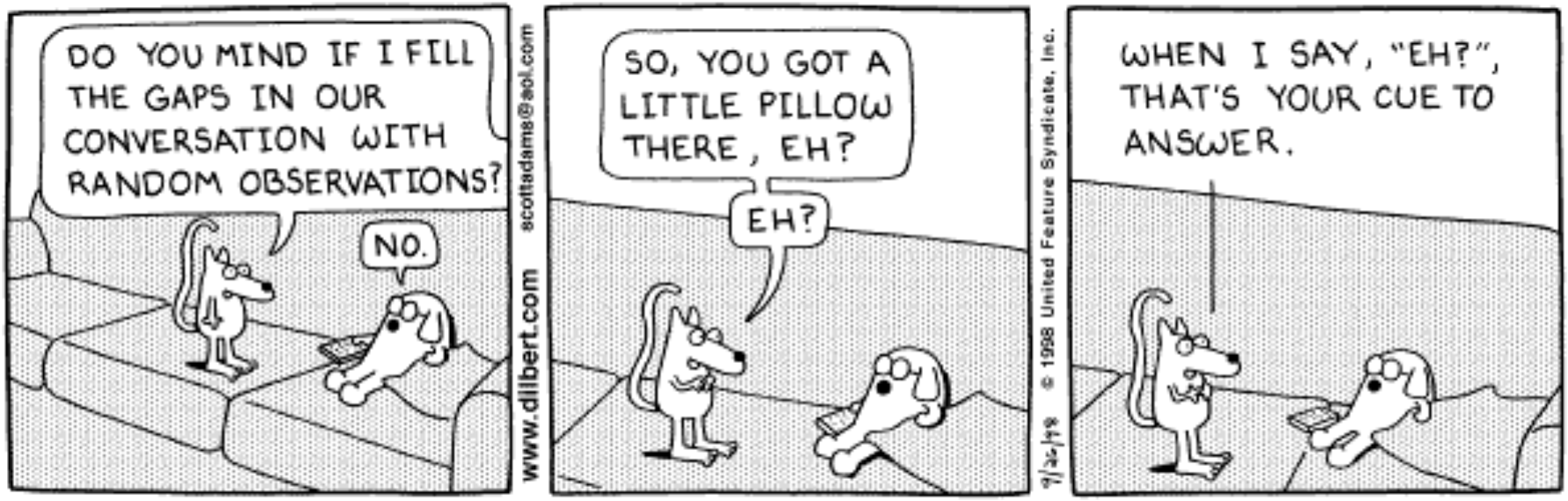
Requesting Feedback



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Some Styles of Verbal Response

1	**Sys:**	Where do you want to go?
2	**User:**	Boston.
3a	**Sys:**	When would you like to go?
3b		Tell me more about your travel plans.
3c		When would you like to go to Boston?
3d		Do you want to go to Boston?
3e		Did you say Boston?
3f		Boston?
3g		Boston or Austin?
3h		Where?
3i		Please Repeat.

Detecting & Verifying ASR Errors: Krahmer et. al. 2001

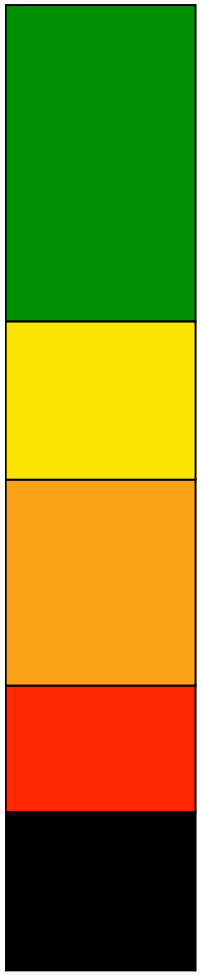
S_1: Good morning, this is the talking computer. From which station to which station do you want to travel?
U_1: From Eindhoven to Reuver.
S_2: On what day do you want to travel from Eindhoven to Winsum?
U_2: I want to travel at 8 'o clock from Eindhoven to Reuver.
S_3: On what day do you want to travel from Eindhoven to Utrecht CS at 8 'o clock in the morning?
U_3: No, in the evening at 8 'o clock I want to travel from Eindhoven to Reuver.
S_4: From which station do you want to travel on Saturday July 18 at 8 'o clock in the morning to Utrecht central station?
U_4: I want to travel tonight at 8 'o clock from Eindhoven to Reuver.
S_5: So you want to travel from Eindhoven to Zutphen today at 20.00?
U_6: No, I want to travel from Eindhoven to Reuver today at 20.00.
S_6: From which station to which station do you want to travel?
etc.

Utterance Features for detecting prior system misunderstandings

- **System**
  - Implicit/Explicit question — When do you want to travel to Amsterdam? / So you want to travel to Amsterdam?
  - Number of verified slots — Date, time, destination, etc.
  - Default assumptions: true? — e.g. travel today
  - Number, type, and recurrence of errors — Human-labeled
- **User**
  - Length (in words)
  - Answer to verification question?
  - Ordinary word order? — I want to go to Amsterdam / Where I want to go is Amsterdam
  - Confirmation/Disconfirmation markers — Yes, no, yeah, nope, etc.
  - Number of repeated, new, and corrected slots

Stereotype of Dialogue System Grounding (from Chuck and Larry)

Immersion and Breakdown (Martinovski & Traum 2003)



- **Immersion: human feels engaged in the conversation, communication feels natural, enjoyable**
  - Focus on task
- **Diagnostic: human having trouble communicating, trying to cooperatively get back to immersion**
  - Focus on communication
- **Breakdown: human gives up, feels unable or unwilling to proceed naturally**
  - Focus on escape/diversion

Strategies for Understanding Errors

- **Prevent them**
  - Structure dialogue to simplify language of user
    - E.g., “please say yes or no”
  - Check correctness of understanding (verification)
    - “I think you said yes, is that correct?”
- **Ignore/minimize them**
  - Structure dialogue to partition responses at a state
  - Predictions of appropriate responses
- **Cope with them**
  - Ground Content: Acknowledge, Request repair, clarify, signal lack of or mis-understanding
    - E.g. "captain i am not understanding you so well"
  - Apologize or take blame: builds social cohesion
    - "my english is not good captain can you repeat that again"
  - Blame user
    - “Stop mumbling”
    - ”you americans, who can understand you”

COMPUTATIONAL MODELS OF GROUNDING II: TRAUM '94

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Computational Model (Traum 94)

- **Contribution recast as "DU" (Discourse Unit)**
  - (later "CGU") (Common Ground Unit)
- **Finite state network for CGU, tracking state of groundedness**
- **Set of Grounding acts to affect contents and state**
- **Interpretation and generation rules**

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Grounding Acts

Label	Description
initiate	Begin new DU, content separate from previous uncompleted DUs
continue	same agent adds related content to open DU
acknowledge	Demonstrate or claim understanding of previous material by other agent
repair	Correct (potential) misunderstanding of DU content
Request Repair	Signal lack of understanding
Request Ack	Signal for other to acknowledge
cancel	Stop work on DU, leaving it ungrounded and ungroundable

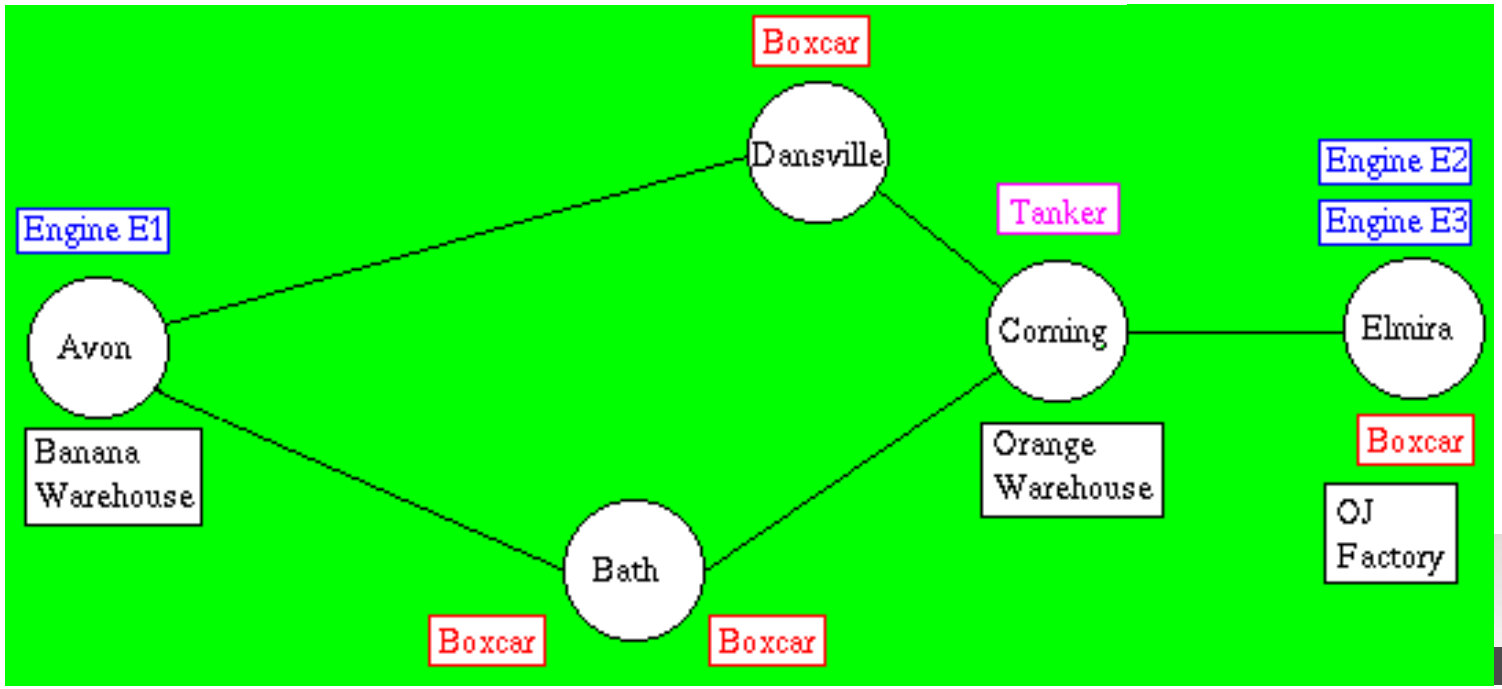
Grounding Automaton

State	Entering Act	Preferred Exiting Act
S	———	Initiate^{I}
1	Initiate^{I}	Ack^{R}
2	ReqRepair^{R}	Repair^{I}
3	Repair^{R}	Ack^{I}
4	ReqRepair^{I}	Repair^{R}
F	$\text{Ack}^{\{I,R\}}$	$\text{Initiate}^{\{I,R\}}$ (next DU)
D	$\text{Cancel}^{\{I,R\}}$	$\text{Initiate}^{\{I,R\}}$ (next DU)

Next Act	In State						
	S	1	2	3	4	F	D
initiate^{I}	1						
continue^{I}		1			4		
continue^{R}			2	3			
repair^{I}		1	1	1	4	1	
repair^{R}		3	2	3	3	3	
ReqRepair^{I}			4	4	4	4	
ReqRepair^{R}		2	2	2	2	2	
ack^{I}				F	1	F	
ack^{R}		F	F			F	
ReqAck^{I}		1				1	
ReqAck^{R}				3		3	
cancel^{I}		D	D	D	D	D	
cancel^{R}			1	1		D	

TRAINS Domain (Allen et al 1994)

```
Manager: We better ship a boxcar of oranges to Bath by eight a.m.        (1.1)
System: OK                                                               (2.1)
Manager: So we need to get a boxcar to Corning, where there are oranges. (3.1)
         There are oranges at Corning.                                   (3.2)
         Right?                                                          (3.3)
System: Right                                                            (4.1)
Manager: So we need an engine to move the boxcar.                        (5.1)
         Right?                                                          (5.2)
System: Right                                                            (6.1)
Manager: So there's an engine at Avon.                                   (7.1)
         Right?                                                          (7.2)
System: Right                                                            (8.1)
Manager: So we should move the engine at Avon, engine E1, to Dansville
         to pick up the boxcar there                                     (9.1)
System: Okay                                                             (10.1)
Manager: and move it from Dansville to Corning                           (11.1)
         load up some oranges in the boxcar                              (11.2)
         and then move it on to Bath                                     (11.3)
System: Okay                                                             (12.1)
Manager: How does that sound?                                            (13.1)
System: That's no problem                                                (14.1)
Manager: Good                                                            (15.1)
```



Grounding Example: Trains Domain

(1)

1	I: Move the boxcar to Corning
2	I: and load it with oranges
3	R: ok

(2)

1	I: Move the boxcar to Corning
2	R: ok
3	I: and load it with oranges
4	R: ok

(3)

utt:	Grounding Act	DU1
1:	$\text{init}^{\text{I}}(1)$	1
2:	$\text{cont}^{\text{I}}(1)$	1
3:	$\text{ack}^{\text{R}}(1)$	F

(4)

utt:	Grounding Act	DU1	DU2
1:	$\text{init}^{\text{I}}(1)$	1	
2:	$\text{ack}^{\text{R}}(1)$	F	
3:	$\text{init}^{\text{I}}(2)$	F	1
4:	$\text{ack}^{\text{R}}(2)$	F	F

Grounding Example: Trains Domain

UU#	Speaker: Utterance		Act(s)	DU States 1	2	3	4
3.3	M: let's see	:	$init_1$	1			
3.4	: where are there oranges	:	$cont_1$	1			
4.1	S: the oranges are in the warehouse	:	ack_1,$init_2$	F	1		
4.2	: at Corning	:	$cont_2$	F	1		
5.1	M: oh okay	:	ack_2	F	F		
5.2	: and I see that there's a tanker car there	:	$init_3$	F	F	1	
5.3	: oh we don't want a tanker car do we	:	$cancel_3$	F	F	D	
5.4	: um	:		F	F	D	
5.5	: I have to get a boxcar	:	$init_4$	F	F	D	1
5.6	: to Corning	:	$cont_4$	F	F	D	1
5.7	: and then I have to load it with oranges and eventually I have to get that to Bath	:	$cont_4$	F	F	D	1
5.8	: by 8 o'clock	:	$cont_4$	F	F	D	1
6.1	S: right	:	ack_4	F	F	D	F

Recognizing Grounding Acts

- **Initiate: core acts, no ungrounded CGU**
- **acknowledge: evidence of understanding (backward act, explicit, follow-up)**
- **Request-repair: clarify-parameter, or repetition request**
- **Repair: providing changing or solicited info**

Grounding Act Updates

- **initiate:**
  - New CGU, state -> 1, obligation to ground
- **continue:**
  - New content added to CGU
- **Request-repair**
  - State -> 2, obligation to repair
- **Repair**
  - State-> 1, change content
- **Acknowledge**
  - State -> F, content effects
- **Cancel**
  - State -> D, remove CGU from ^grounding, recent-cgus, remove grounding obligations for CGU

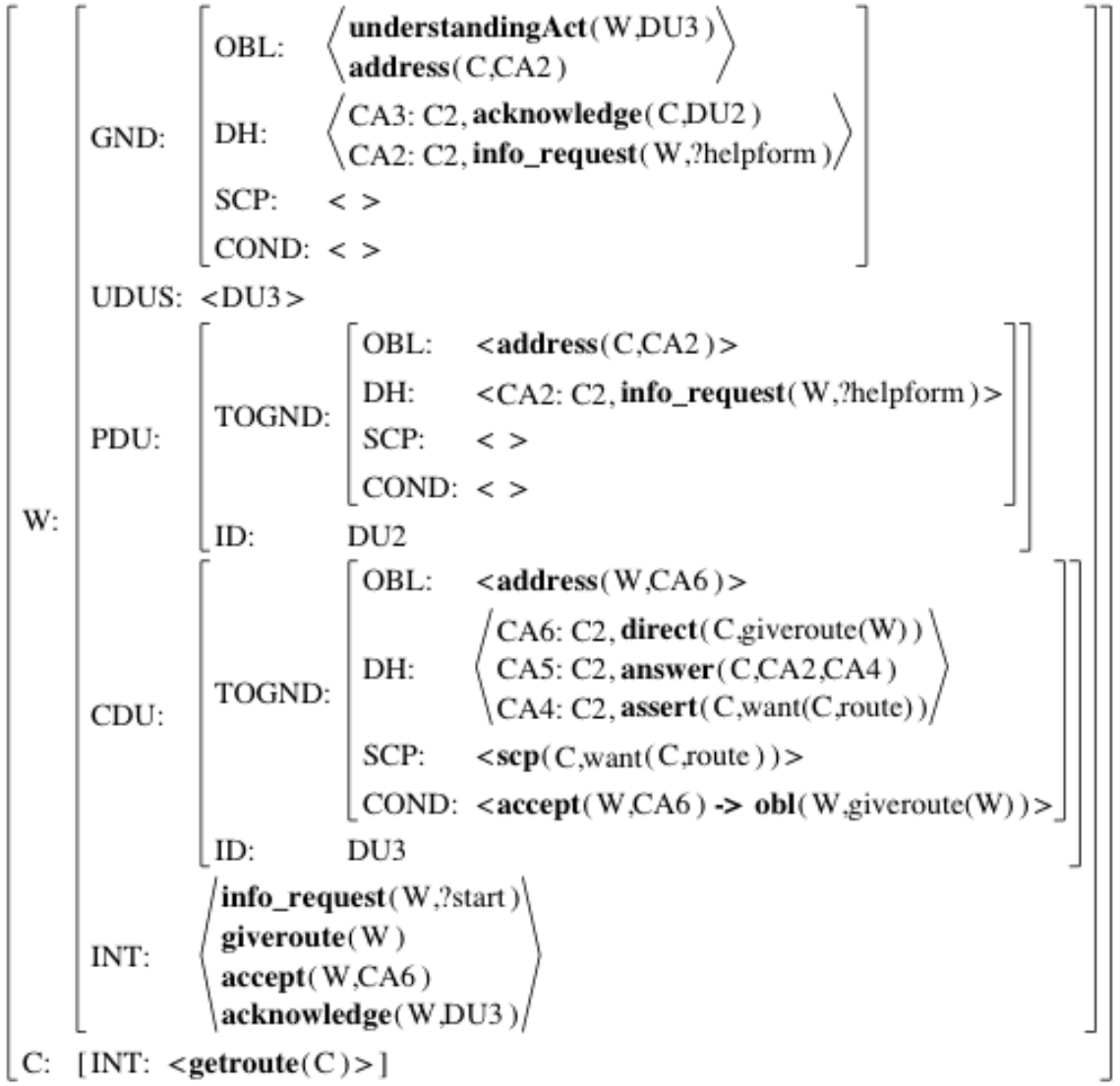
EDIS SYSTEM

- **Uses PTT theory**
- **Trindikit implementation**
- **Autoroute domain**

Sample Autoroute Dialogue

WIZARD	CALLER
[1]: How can I help you?	
	[2]: A route please
[3]: Where would you like to start?	
	[4]: Malvern
[5]: Great Malvern?	
	[6]: Yes
[7]: Where do you want to go?	
	[8]: Edwinstowe
[9]: Edwinstowe in Nottingham?	
	[10]: Yes
[11]: When do you want to leave?	
	[12]: Six pm
[13]: Leaving at 6 p.m.?	
	[14]: Yes
[15]: Do you want the quickest or the shortest route?	
	[16]: Quickest
[17]: Please wait while your route is calculated.	

InfoState after [2]: A route please



InfoState after [4]: Malvern, prompting check

$$
\begin{bmatrix}
\text{W:} & \begin{bmatrix}
\text{GND:} & \begin{bmatrix}
\text{OBL:} & \left\langle \begin{array}{l} \textbf{giveroute}(\text{W}) \\ \textbf{understandingAct}(\text{W},\text{DU5}) \\ \textbf{address}(\text{C},\text{CA8}) \end{array} \right\rangle \\
\text{DH:} & \left\langle \begin{array}{l} \text{CA10: C2}, \textbf{acknowledge}(\text{C},\text{DU4}) \\ \text{CA9: C2}, \textbf{accept}(\text{W},\text{CA6}) \\ \text{CA8: C2}, \textbf{info\_request}(\text{W},?\text{start}) \end{array} \right\rangle \\
\text{SCP:} & < > \\
\text{COND:} & < >
\end{bmatrix} \\
\text{UDUS:} & <\text{DU5}> \\
\text{PDU:} & \begin{bmatrix}
\text{TOGND:} & \begin{bmatrix}
\text{OBL:} & <\textbf{address}(\text{C},\text{CA8})> \\
\text{DH:} & \left\langle \begin{array}{l} \text{CA9: C2}, \textbf{accept}(\text{W},\text{CA6}) \\ \text{CA8: C2}, \textbf{info\_request}(\text{W},?\text{start}) \end{array} \right\rangle \\
\text{SCP:} & < > \\
\text{COND:} & < >
\end{bmatrix} \\
\text{ID:} & \text{DU4}
\end{bmatrix} \\
\text{CDU:} & \begin{bmatrix}
\text{TOGND:} & \begin{bmatrix}
\text{OBL:} & < > \\
\text{DH:} & \left\langle \begin{array}{l} \text{CA12: C2}, \textbf{answer}(\text{C},\text{CA8},\text{CA11}) \\ \text{CA11: C1}, \textbf{assert}(\text{C},\text{start(malvern)}) \end{array} \right\rangle \\
\text{SCP:} & < > \\
\text{COND:} & < >
\end{bmatrix} \\
\text{ID:} & \text{DU5}
\end{bmatrix} \\
\text{INT:} & \left\langle \begin{array}{l} \textbf{check}(\text{W},\text{start(malvern)}) \\ \textbf{acknowledge}(\text{W},\text{DU5}) \\ \textbf{giveroute}(\text{W}) \end{array} \right\rangle
\end{bmatrix} \\
\text{C:} & [\text{INT: } <\textbf{getroute}(\text{C})>]
\end{bmatrix}
$$

InfoState after [5]: Great Malvern?

$$
\begin{bmatrix}
W: & \begin{bmatrix}
\text{GND:} & \begin{bmatrix}
\text{OBL:} & \left\langle \begin{array}{l} \textbf{understandingAct}(\text{C},\text{DU6}) \\ \textbf{giveroute}(\text{W}) \end{array} \right\rangle \\
\text{DH:} & \left\langle \begin{array}{l} \text{CA13: C2}, \textbf{acknowledge}(\text{W},\text{DU5}) \\ \text{CA12: C2}, \textbf{answer}(\text{C},\text{CA8}) \\ \text{CA11: C1}, \textbf{assert}(\text{C},\text{start(malvern)}) \end{array} \right\rangle \\
\text{SCP:} & < > \\
\text{COND:} & < >
\end{bmatrix} \\
\text{UDUS:} & <\text{DU6}> \\
\text{PDU:} & \begin{bmatrix}
\text{TOGND:} & \begin{bmatrix}
\text{OBL:} & < > \\
\text{DH:} & \left\langle \begin{array}{l} \text{CA12: C2}, \textbf{answer}(\text{C},\text{CA8},\text{CA11}) \\ \text{CA11: C1}, \textbf{assert}(\text{C},\text{start(malvern)}) \end{array} \right\rangle \\
\text{SCP:} & < > \\
\text{COND:} & < >
\end{bmatrix} \\
\text{ID:} & \text{DU5}
\end{bmatrix} \\
\text{CDU:} & \begin{bmatrix}
\text{TOGND:} & \begin{bmatrix}
\text{OBL:} & <\textbf{address}(\text{C},\text{CA14})> \\
\text{DH:} & <\text{CA14: C2}, \textbf{check}(\text{W},\text{start(malvern)})> \\
\text{SCP:} & < > \\
\text{COND:} & <\textbf{agree}(\text{C},\text{CA14}) \textbf{ -> scp}(\text{W},\text{start(malvern)})>
\end{bmatrix} \\
\text{ID:} & \text{DU6}
\end{bmatrix} \\
\text{INT:} & <\textbf{giveroute}(\text{W})>
\end{bmatrix} \\
\text{C:} & [\text{INT: } <\textbf{getroute}(\text{C})>]
\end{bmatrix}
$$

InfoState after [7]: Where do you want to go?

$$
\begin{bmatrix}
W: & \begin{bmatrix}
\text{GND:} & \begin{bmatrix}
\text{OBL:} & \left\langle \begin{array}{l} \textbf{understandingAct}(\text{C},\text{DU8}) \\ \textbf{giveroute}(\text{W}) \end{array} \right\rangle \\
\text{DH:} & \left\langle \begin{array}{l} \text{CA17: C2}, \textbf{acknowledge}(\text{W},\text{DU7}) \\ \text{CA16: C2}, \textbf{agree}(\text{C},\text{CA14}) \end{array} \right\rangle \\
\text{SCP:} & \left\langle \begin{array}{l} \textbf{scp}(\text{C},\textbf{start}(\text{malvern})) \\ \textbf{scp}(\text{W},\textbf{start}(\text{malvern})) \end{array} \right\rangle \\
\text{COND:} & \langle\ \rangle
\end{bmatrix} \\
\text{UDUS:} & \langle \text{DU8} \rangle \\
\text{PDU:} & \begin{bmatrix}
\text{TOGND:} & \begin{bmatrix}
\text{OBL:} & \langle\ \rangle \\
\text{DH:} & \langle \text{CA16: C2}, \textbf{agree}(\text{C},\text{CA14}) \rangle \\
\text{SCP:} & \langle \textbf{scp}(\text{C},\textbf{start}(\text{malvern})) \rangle \\
\text{COND:} & \langle\ \rangle
\end{bmatrix} \\
\text{ID:} & \text{DU7}
\end{bmatrix} \\
\text{CDU:} & \begin{bmatrix}
\text{TOGND:} & \begin{bmatrix}
\text{OBL:} & \langle \textbf{address}(\text{C},\text{CA18}) \rangle \\
\text{DH:} & \langle \text{CA18: C2}, \textbf{info\_request}(\text{W},?\text{dest}) \rangle \\
\text{SCP:} & \langle\ \rangle \\
\text{COND:} & \langle\ \rangle
\end{bmatrix} \\
\text{ID:} & \text{DU8}
\end{bmatrix} \\
\text{INT:} & \langle \textbf{giveroute}(\text{W}) \rangle
\end{bmatrix} \\
\text{C:} & [\text{INT:}\ \langle \textbf{getroute}(\text{C}) \rangle]
\end{bmatrix}
$$

Problems with this Model
(later work addressing these issues)

- **Binary grounded/ungrounded decision**
  - No levels of "groundedness" (Roque 2009)
- **Leaves the unit size unspecified** (Visser, DeVault & Traum)
- **Confusability of grounding acts**
  - e.g. repetition = acknowledgment, repair, or request for repair? (Katagiri & Shimojima)
- **Only well-suited for spoken language grounding**
  - Different kinds and meanings of non-verbal feedback (Nakano et al 2003)
  - Less explicit signaling in computer-mediated chat (Dillenbourg & Traum)