# ESSLLI2022 Advanced Course on Computational Models of Grounding in Dialogue

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# Outline of Course (covered today)

- Preliminaries: representation, agency, communication, definitions & uses for common ground
- Common Ground: How it is modeled and achieved
- Clark & Schaefer's Model of Grounding
- Computational Models of Grounding I: Brennan & Cahn
- Feedback and Error-handling in Spoken Dialogue Systems
- Speech Acts and Dialogue Acts
- Multi-functionality of Utterances
- **Computational Models of Grounding II: Traum '94**
- **Multi-modal Grounding**
- **Decision-theoretic models of grounding**
- **Multiparty Multilingual & Multi-floor Grounding**
- **Degrees of Grounding**
- **Incremental Grounding**
- **Use of grounding for other phenomena**

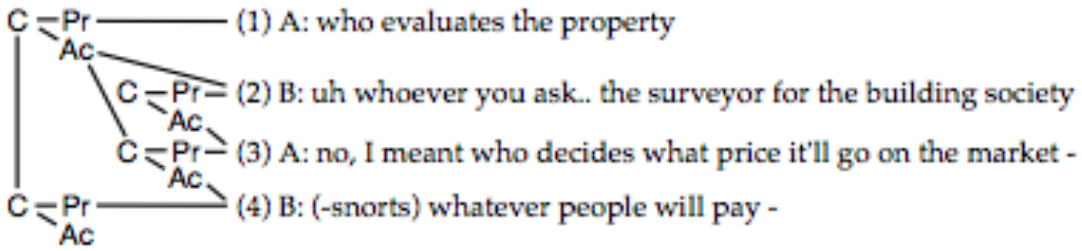
# REVIEW OF YESTERDAY

# Brennan & Cahn 1999: Extensions to Clark and Schaefer

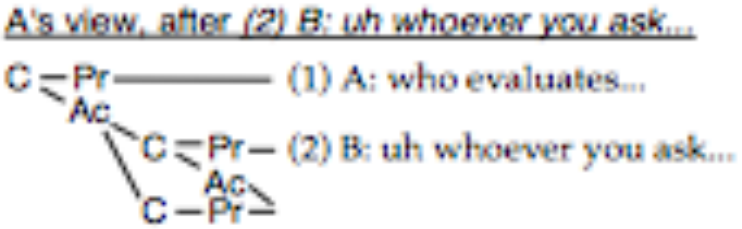
1. **All contribution graphs are private models from an individual's point of view**
   - C&S graph seen as composite final product
   - Incrementally constructed, utterance by utterance
2. **Task-specific heuristics for assessing evidence of understanding and grounding criterion**
3. **Principles for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

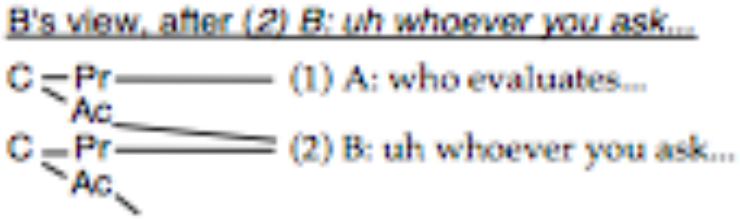
# Brennan & Cahn 1999:

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




  - B&C:



# Types of Feedback (Allwood et al 92)

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

# 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. |

# 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”

# Speech Acts (Austin)

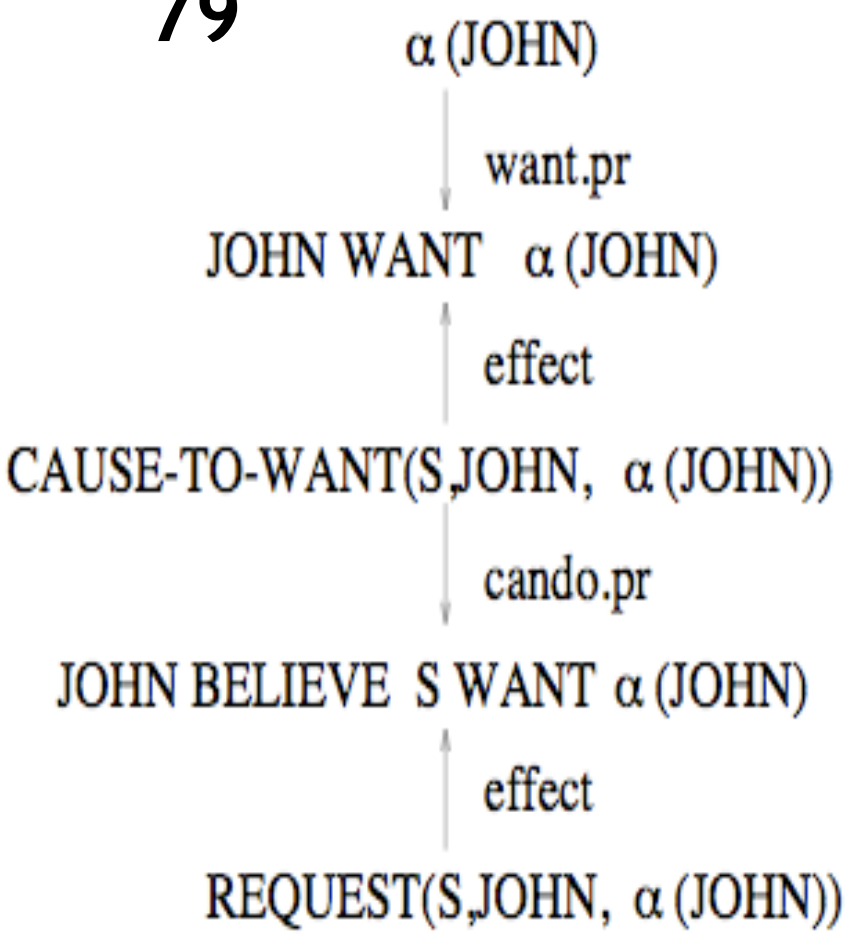
- **How to "Do things" with words**
  - Look at actions & effects of utterances rather than truth-conditions
  - Types of acts
    - Locutionary
    - Illocutionary
    - Perlocutionary

# 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?**

# 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

# 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?**

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**Dimensions of communication in dialogue:**

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

# 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 |

# COMPUTATIONAL MODELS OF GROUNDING II: TRAUM '94

# 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**

# 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 |

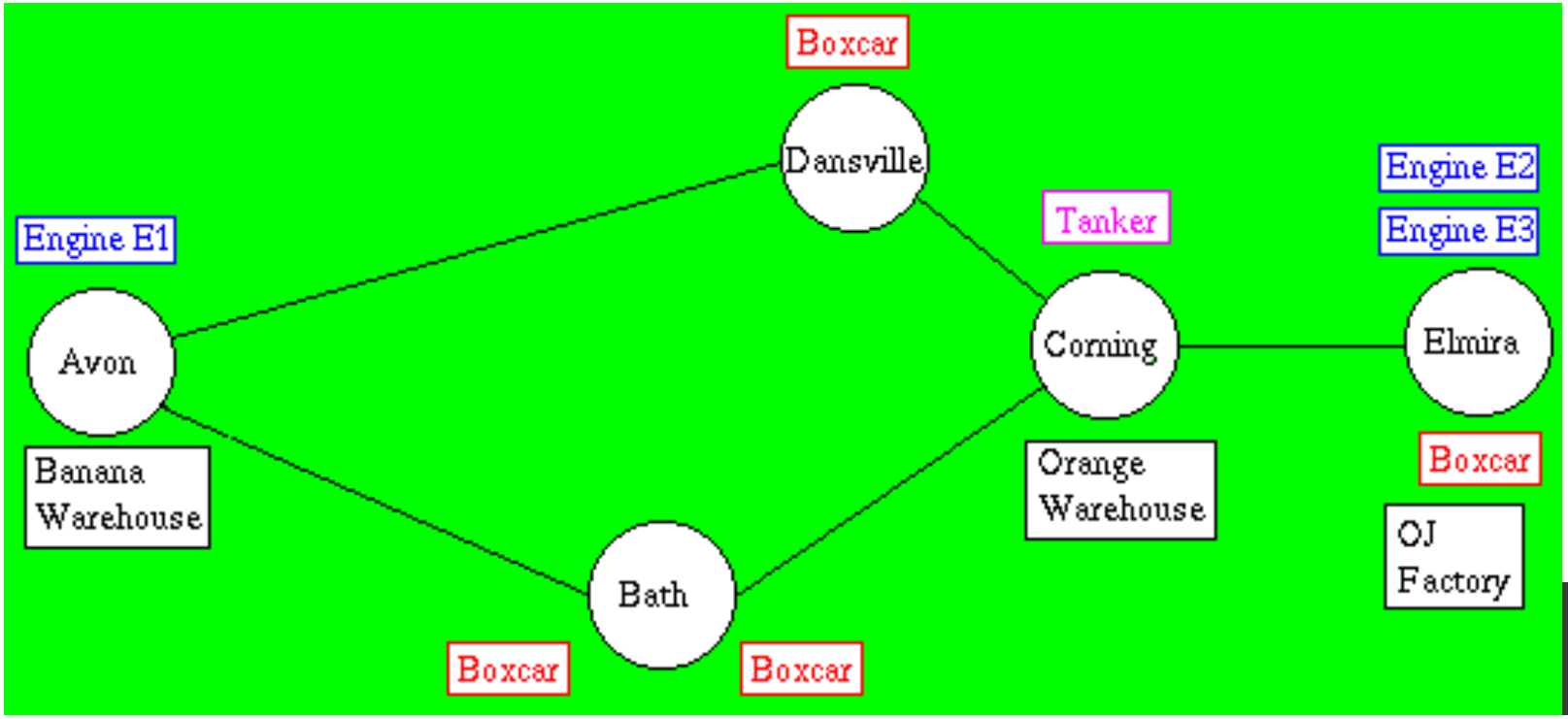
# Grounding Automaton

| State | Entering Act | Preferred Exiting Act |
|---|---|---|
| S | ——— | $\text{Initiate}^{I}$ |
| 1 | $\text{Initiate}^{I}$ | $\text{Ack}^{R}$ |
| 2 | $\text{ReqRepair}^{R}$ | $\text{Repair}^{I}$ |
| 3 | $\text{Repair}^{R}$ | $\text{Ack}^{I}$ |
| 4 | $\text{ReqRepair}^{I}$ | $\text{Repair}^{R}$ |
| 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 -> 2,4 obligation to repair
- **Repair**
  - State-> 1,3 change content
- **Acknowledge**
  - State -> F, content effects
- **Cancel**
  - State -> D, remove CGU from ^grounding, recent-cgus, remove grounding obligations for CGU

# Di Maro (2021) review of work relating to each of the types of grounding act from Traum (1994).

| Grounding Act | References |
|---|---|
| Initiate | (Dahlbäck and Jönsson 1998) |
| Continue | (Schlangen and Skantze 2011) (Visser et al. 2012) (Visser et al. 2014) |
| Acknowledgement | (Skantze, House, and Edlund 2006) (Wang, Lee, and Marsella 2013) (Visser et al. 2012, 2014) (Eshghi et al. 2015) (Buschmeier 2018) (Buschmeier and Kopp 2018) (Schlangen 2019) |
| Repair | (Skantze 2008) (Swerts, Litman, and Hirschberg 2000) (Hough and Purver 2012) (Marge and Rudnicky 2015) (Purver, Hough, and Howes 2018) (Di Maro et al. 2019) (Marge and Rudnicky 2019) |
| Cancel | N/A |
| RequestRepair | (Gabsdil 2003) (Rodríguez and Schlangen 2004) (Purver 2004a) (Schlangen 2004) (Purver 2006) (Stoyanchev, Liu, and Hirschberg 2014) (Müller, Paul, and Li 2021) |
| RequestAcknowledgement | (Misu et al. 2011) (Buschmeier and Kopp 2014) |

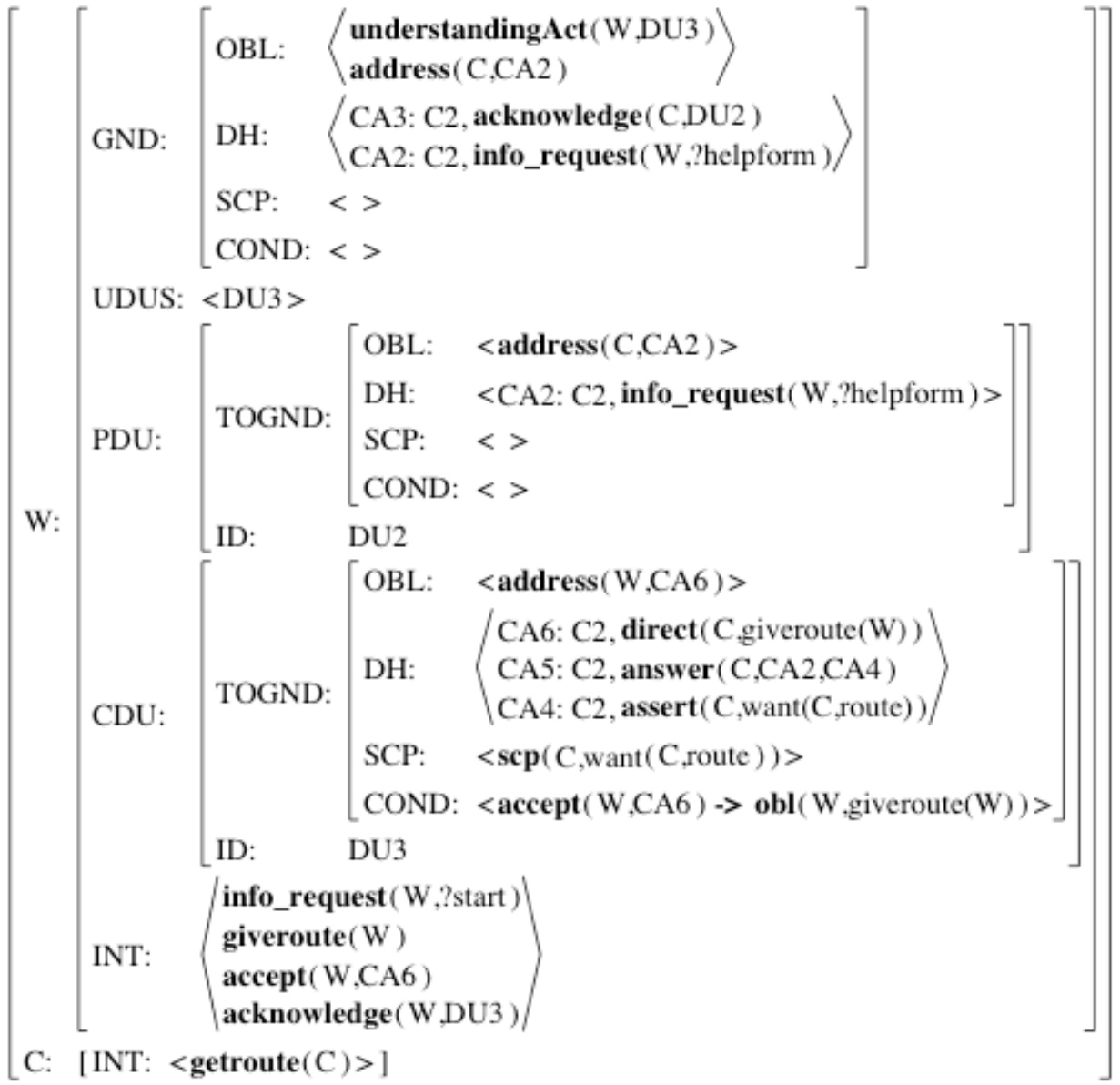
# EDIS SYSTEM

- 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

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

# InfoState after [5]: Great Malvern?

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

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

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

# 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)

# Display Act (Katagiri & Shimojima 2000)

- **Problem for Clark & Shaefer 92 & Traum 94: display of responder's understanding might be acceptance/acknowledgement, Repair, request repair**
- **Depends on initiator's determination of (in-)correctness and responder's projected certainty.**
- **Propose lower-level "display" act, that can be interpreted by initiator**

| Generating Act ($\alpha$) | | Context | Generated Act ($\beta$) |
|---|---|---|---|
| Content | Result | Target | |
| "uh huh" | | following $p$ | acknowledgment |
| "what?" | | following $p$ | repair request |
| display $p$ | High | following $p$ | acknowledgment |
| display $p'$ | High | following $p$ | repair |
| display $p$ | Neutral | following $p$ | acknowledgment |
| display $p'$ | Neutral | following $p$ | repair request |
| display $p$ | Low | following $p$ | repair request |
| display $p'$ | Low | following $p$ | repair request |

Table 1: Grounding acts generated by echoic responses.

# MULTI-MODAL GROUNDING

# Multimodal Grounding: Key questions

- What evidence signals can be performed in modality
- What affordances (constraints) does modality place on achieving/assuming common ground?
- Multifunctionality
- Within and cross-grounding

# Clark & Brennan '91: Constraints on Grounding

- 1. *Copresence: A and B share the same physical environment.* In face-to- face conversation, the participants are usually in the same surroundings and can readily see and hear what each other is doing and looking at. In other media there is no such possibility.
- 2. *Visibility: A and B are visible to each other.* In face-to-face conversation, the participants can see each other, and in other media they cannot. They may also be able to see each other, as in video teleconferencing, without being able to see what each other is doing or looking at.
- 3. *Audibility: A and B communicate by speaking.* Face to face, on the telephone, and with some kinds of teleconferencing, participants can hear each other and take note of timing and intonation. In other media they cannot. An answering machine preserves intonation, but only some aspects of utterance timing.

# Clark & Brennan '91: Constraints on Grounding

- **4. *Cotemporality: B receives at roughly the same time as A produces.* In most conversations, an utterance is produced just about when it is received and understood, without delay. In media such as letters and electronic mail, this is not the case.**
- ***5. Simultaneity: A and B can send and receive at once and simultaneously.* Sometimes messages can be conveyed and received by both parties at once, as when a hearer smiles during a speaker's utterance. Simultaneous utterances are also allowed, for example, in the keyboard teleconferencing program called *talk,* where what both parties type appears letter by letter in two distinct halves of the screen. Other media are cotemporal but not simultaneous, such as the kind of keyboard teleconferencing that transmits characters only after the typist hits a carriage return.**

# Clark & Brennan '91: Constraints on Grounding

- 6. ***Sequentiality: A's and B's turns cannot get out*** **of** ***sequence.*** **In face-to-face conversation, turns ordinarily form a sequence that does not include intervening turns from different conversations with other people. With email, answering machines, and letters, a message and its reply may be separated by any number of irrelevant messages or activities; interruptions do not have the same force.**
- 7. ***Reviewability: B can review A's messages.*** **Speech fades quickly, but in media such as email, letters, and recorded messages, an utterance stays behind as an artifact that can be reviewed later by either of the partners—or even by a third party. In keyboard teleconferencing, the last few utterances stay visible on the screen for awhile.**
- 8. ***Revisability: A can revise messages for B.*** **Some media, such as letters and email, allow a participant to revise an utterance privately before sending it to a partner. In face-to-face and telephone conversations, most self-repairs must be done publicly. Some kinds of keyboard teleconferencing fall in between; what a person types appears on the partner's screen only after every carriage return, rather than letter by letter.**

# Clark & Brennan '91: Media constraints on Grounding

SEVEN MEDIA AND THEIR ASSOCIATED CONSTRAINTS

| Medium | Constraints |
|---|---|
| Face-to-face | Copresence, visibility, audibility, cotemporality, simultaneity, sequentiality |
| Telephone | Audibility, cotemporality, simultaneity, sequentiality |
| Video teleconference | Visibility, audibility, cotemporality, simultaneity, sequentiality |
| Terminal teleconference | Cotemporality, sequentiality, reviewability |
| Answering machines | Audibility, reviewability |
| Electronic mail | Reviewability, revisability |
| Letters | Reviewability, revisability |

# Media and Activity factors in Grounding

- **Clark and Brennan 90**
  - Media influences amount and type of grounding
- **E.g., Traum & Heeman '96: Trains Domain, spoken language, no visual contact**

| Category | % utterances |
|---|---|
| Explicit Ack | 52% |
| Related | 29% |
| Unrelated after Explicit | 15% |
| Other Unrelated | 3% |
| Uncertain | 2% |

# Dillenbourg & Traum 96, 05
## Multi-modal computer-mediated grounding

- **Collaborative dyadic interaction**
  - Mystery solving
- **Multiple (distant) modalities**
  - Moo (including 2-3 kinds of chat)
  - Shared Whiteboard
  - Private notebook (stored learned facts)
- **Extended interactions**
  - 45 min – 2 hrs

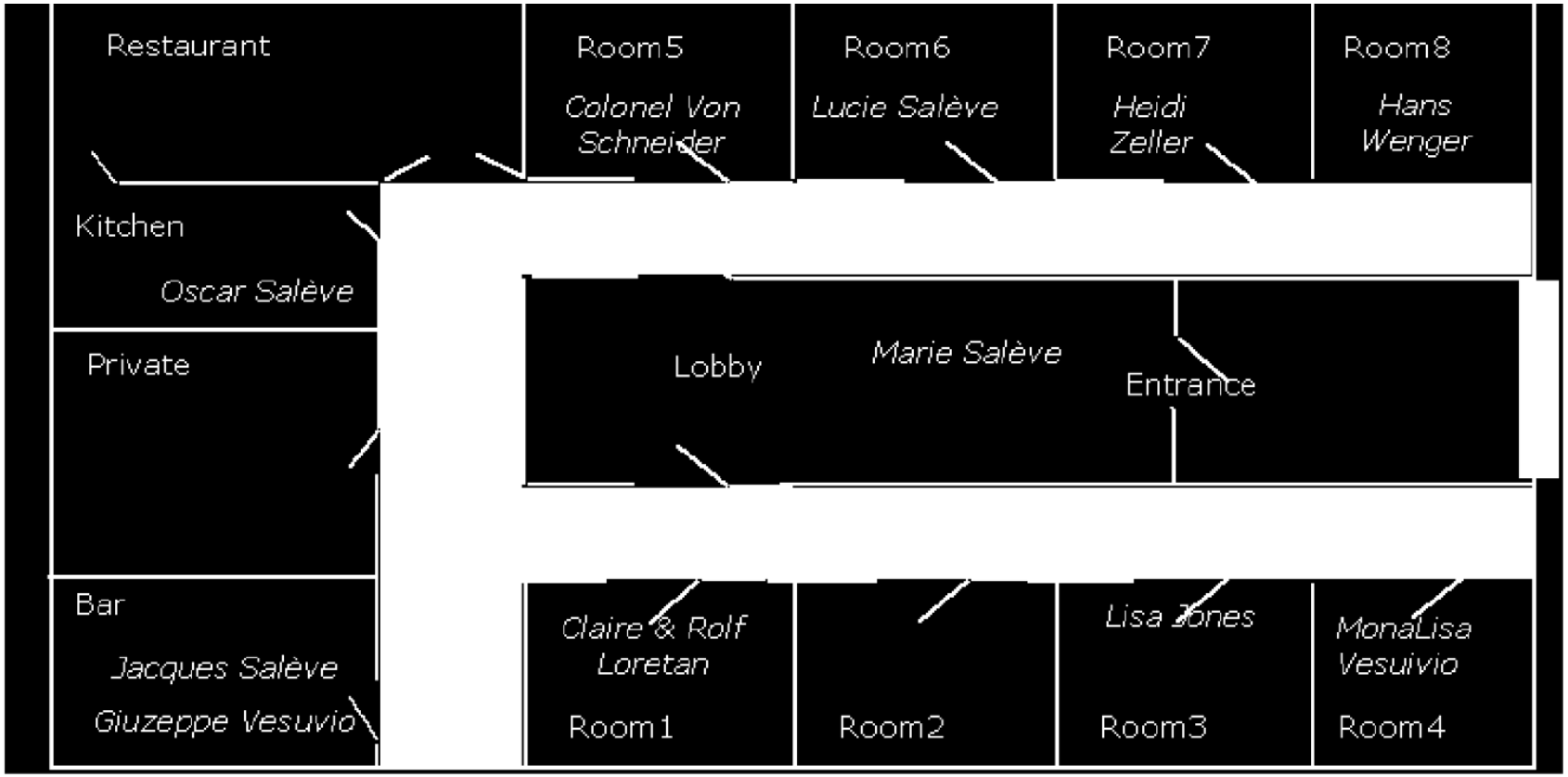
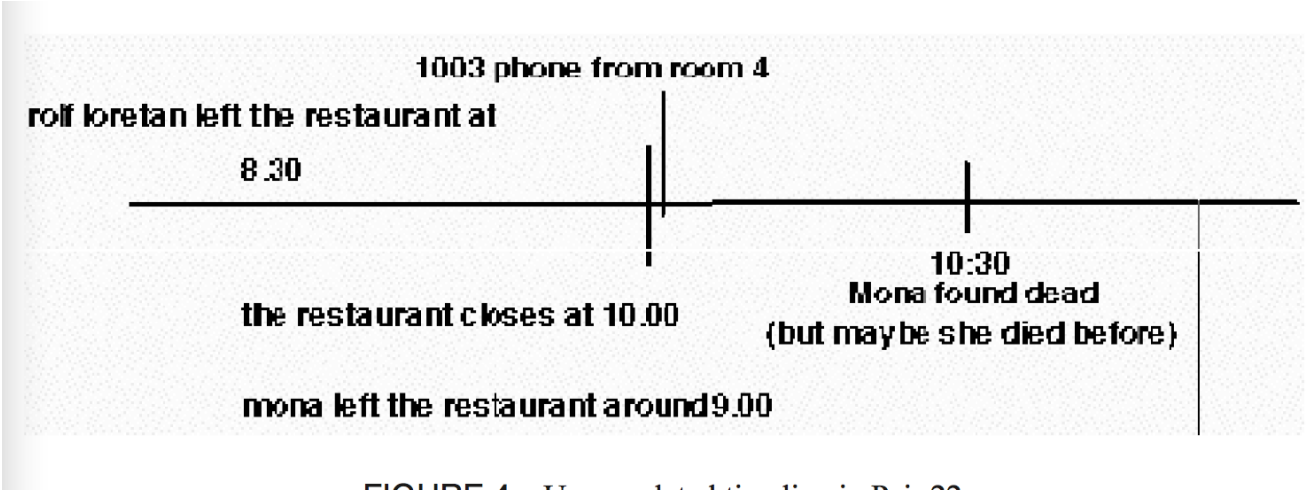


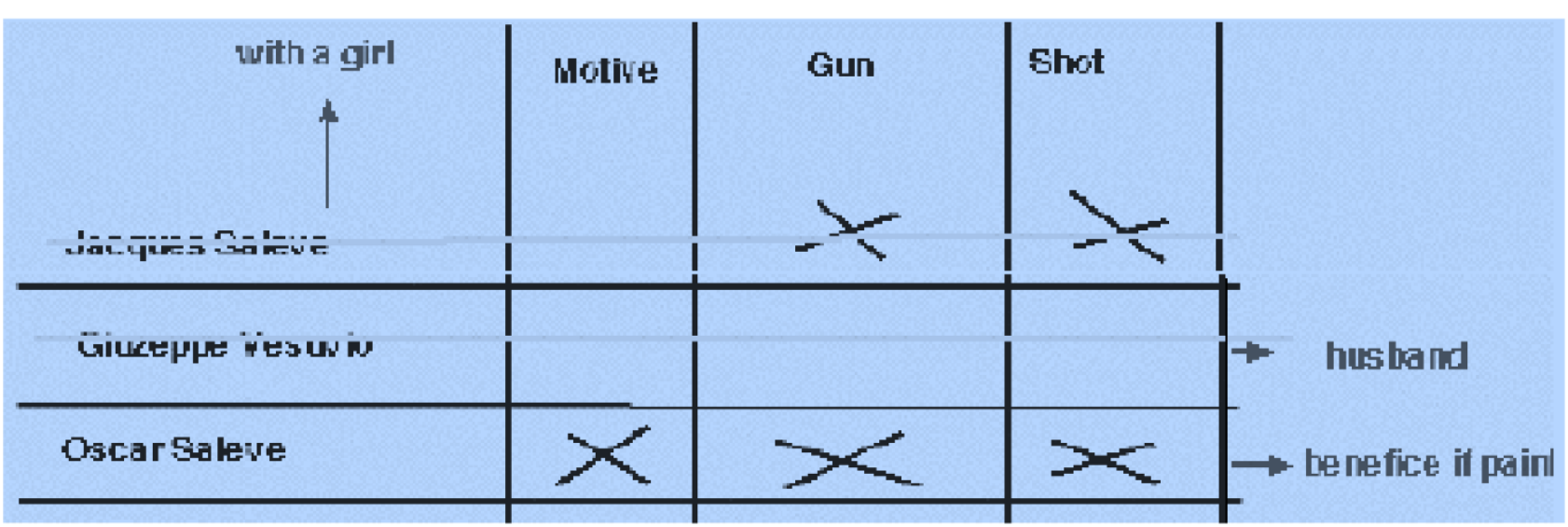

FIGURE 1 A map of the hotel participants received and had to explore.

**join sherlock**
Hotel du Bout de Nappe: Lower Corridor
Obvious Exits: Lobby (to Lobby), UC (to Upper Corridor), B (to Bar), P (to Private Residence), R1 (to 1), R2 (to 2), R3 (to 3), and R4 (to 4).
Hotel Guest Room: 1
You see Rolf Loretan and Claire Loretan here.
Sherlock is here.
Obvious Exits: Out (to Lower Corridor).
Sherlock asks Claire Loretan about last night
Claire Loretan answers "I was in the restaurant with my husband and the Vesuvios. When the restaurant closed, I briefly went to my room and then joined the others in the bar."
Sherlock asks "Do you know when the bar has closed?"
**wisper Did you notice that he is an insurance agent?**
I don't understand that.
**"what are doing?**
You ask, "what are doing?"
**ask rolf about the gun**
hercule asks Rolf Loretan about the gun
Rolf Loretan answers "it looks like a military issue gun. Why don't you ask that Colonel?"
Sherlock says "Forget it. I thought it could help if we make a tab with the informations about where were th people at what time."
**"Actually sounds a good idea.**
You say, "Actually sounds a good idea. "
"I think we should find more information about the gun
You say, "I think we should find more information about the gun"

FIGURE 2 An excerpt from the MOO window.

# Example Whiteboard constructions

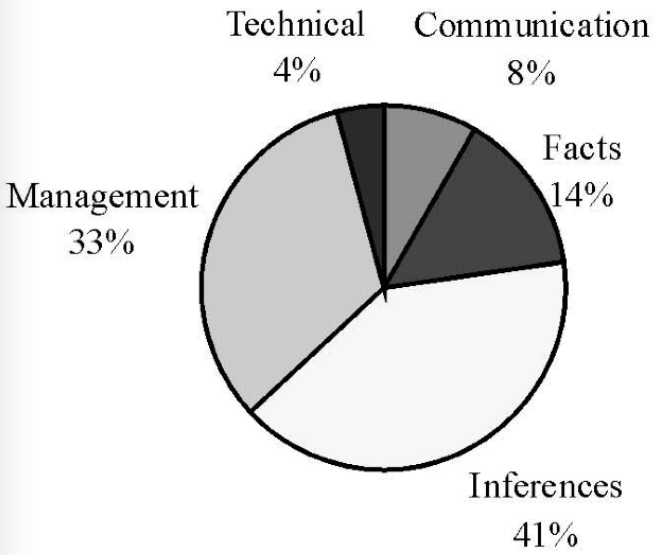


# Knowledge Categories

TABLE 4
Content Categories for Analyzing Interactions

| *Category* | *Subcategory* | *Content and Examples* |
|---|---|---|
| Task knowledge | Facts | Utterances that contain information directly obtained from the Moo by the participants (e.g., "Rolf was a colleague of the victim"). These are often word-for-word repetitions of the answer given by a suspect |
| | Inferences | An utterance that involves some interpretation by the participant (e.g., "Helmut had no motive to kill"). |
| Management | | Utterances about how to proceed: How to collect information (which suspects, which rooms, which questions, …), how to organize data, how to prune the set of possible suspects, who does what in the pair, and so on. Utterances regarding spatial positions were generally related to strategy issues and were hence included in this category. |
| Metacommunication | | Utterances about the interaction itself, such as discussing delay in acknowledgment (e.g., "Sorry I was busy with the whiteboard") or establishing conversational rules (e.g., "We should use a color coding"). |
| Technical problems | | Utterances where one participant asks his partner how to perform a particular action in the MOO (e.g., "I can't read my notebook"). |



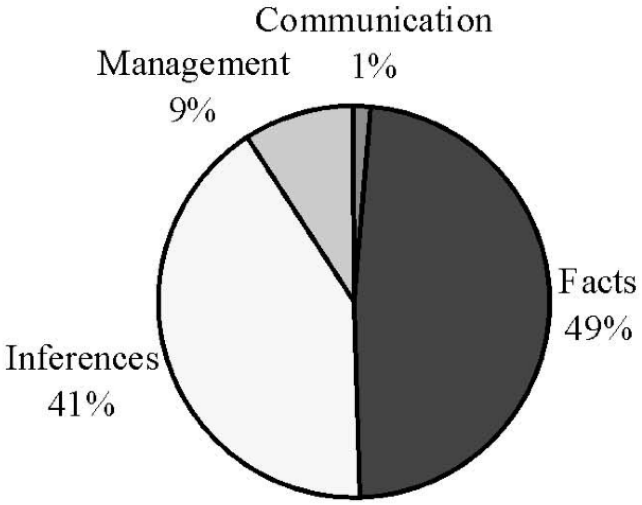




FIGURE 9 Classification of the content of interactions in MOO dialogues (left side) and on whiteboard notes (right side).

# Cross-grounding

TABLE 3
Frequency of Acknowledgment by Modality

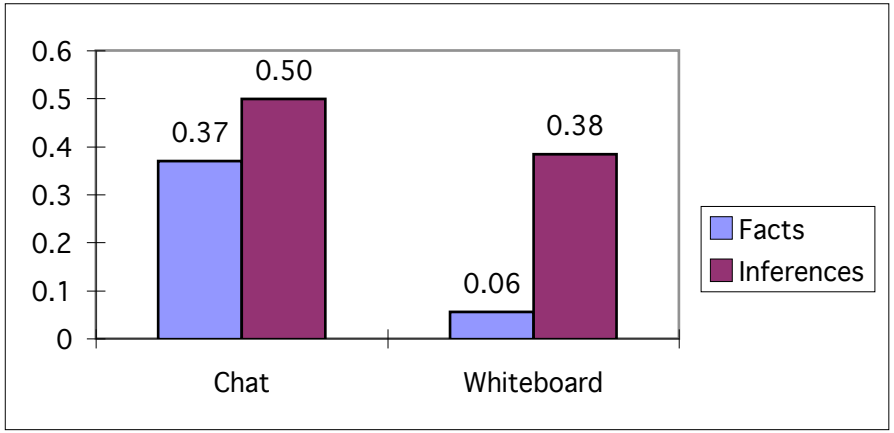
| *Row is Acknowledged by Column* | *Moo Actions* | *MOO Messages* | *Whiteboard* |
|---|---|---|---|
| MOO actions | 2 | 10 | 0 |
| MOO messages | 42 | 1,025 | 34 |
| Whiteboard | 0 | 37 | 35 |

# Dillenbourg & Traum 96, 05
## Multi-modal computer-mediated grounding

- **Grounding by category**

| Content of interactions | Acknowledgment Rate |
|---|---|
| Task knowledge | 38% |
| Facts | 26% |
| Inferences | 46% |
| Task management | 43% |
| Meta-Communication | 55% |
| Technical problems | 30% |
| *All categories* | *41%* |

- **Grounding by Category & Medium**



# Impact of grounding rate on repetition

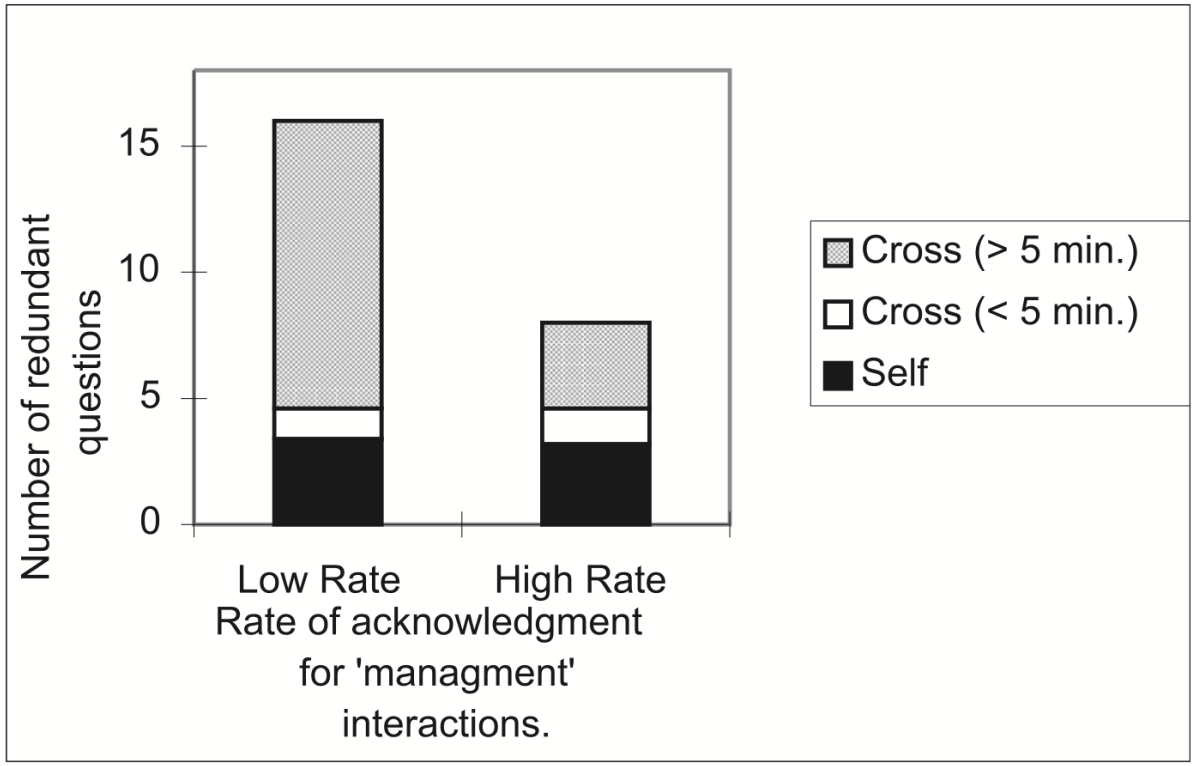



FIGURE 3 Comparison between the number of redundant questions asked by the low acknowledgers (on task management interactions) and high acknowledgers.