I^3 Spring Days Workshop:
Continuity in Future Computing Systems

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Reasoning about Time in Information Displays

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Motivation

Poor usability can defeat the best *technological* solution.

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How should we design novel interactive devices?

Two challenges faced when designing (re)presentations:

- **Dynamic representations** where the user must perceive changes in the information displayed over time.
- **Limited display capabilities** of many ubiquitous computing devices.

The talk

- In this talk we concentrate on issues of **representation and time**.
- We propose **a model to reason about representational issues** where time is involved.
- We show how the model can be used to **reason about a dynamic information display** representing a (variable) information transfer rate.

This work follows from previous work on representational reasoning in [DH97] and [DCH00].

Representations and Time

- Issues of **representation** are fundamental in **what we perceive** and **the way we think** and solve problems [Hut95].
- The increasing use of **novel physical form factors** is likely to increase the importance of external representations [UI00].
- Time plays an increasingly important role in interaction with **computing** systems while **on the move** and in **constantly changing conditions**.

What impact will time have on how usable our presentations will be?

Representational reasoning

Usability evaluation

- **Empirical methods** (prototyping and testing).
  -
  -
- **Analytic methods** (confronting models of the system with how users are expected to behave).
  -
  -

Representational reasoning

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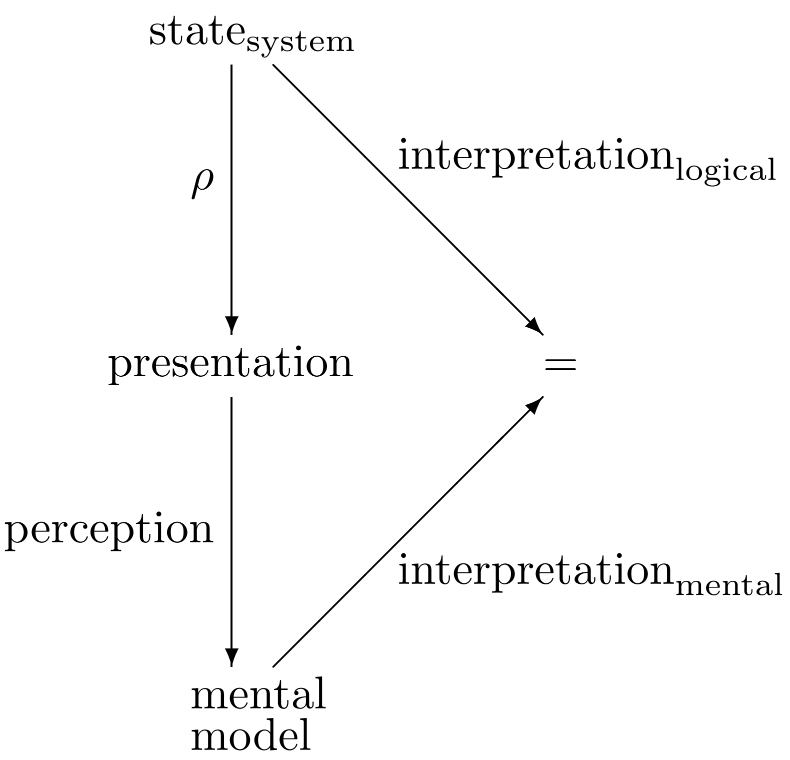
We use **structured models** to allow **rigorous reasoning** about properties of the systems being designed.

How to measure quality

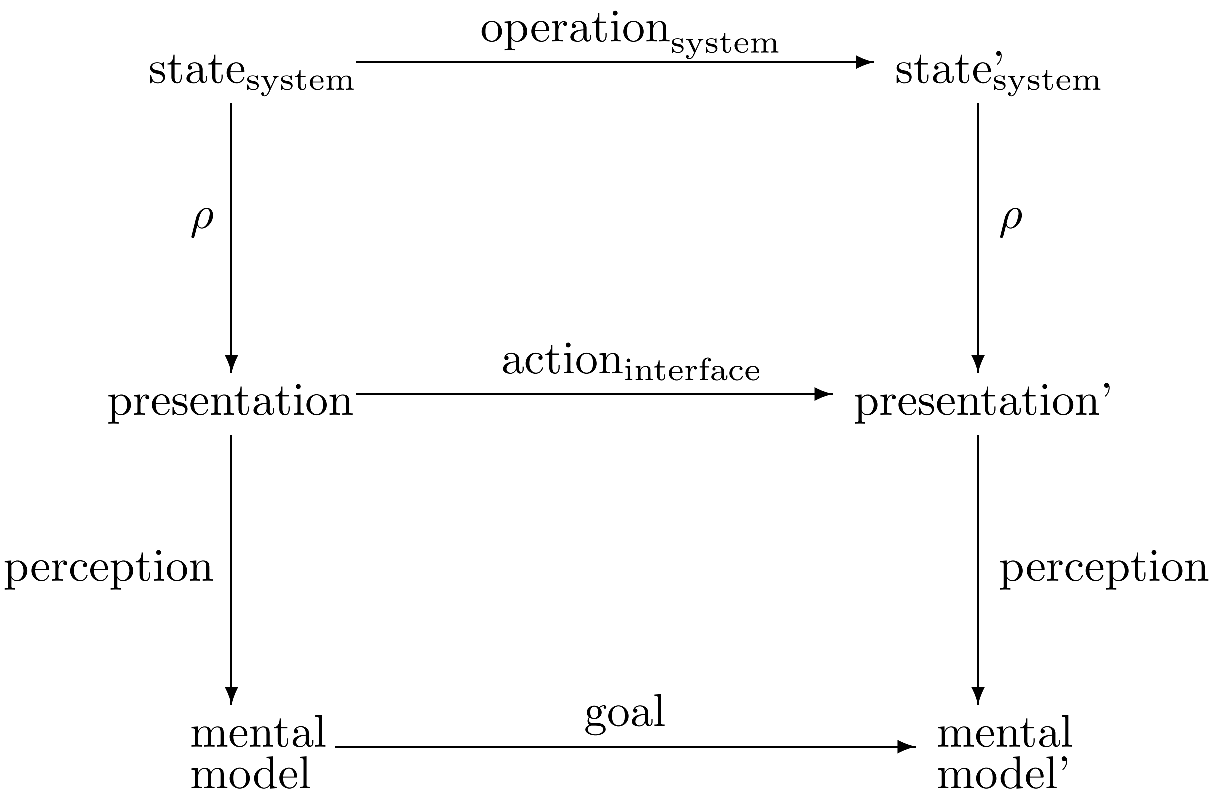
- Conformance to design rules and guidelines?
  - Design rules are too specific for rigorous modelling to be adequate.
  - Guidelines are of qualitative nature, not amenable to rigorous modelling.
  - Design rules and guidelines are of little use when designing novel systems.
- Interactive systems form an increasingly heterogeneous class of systems.
  - Relevant properties vary from system to system.
  - We need to pay attention to what is generally true of all systems and all users

We need a framework which illustrates qualitative differences between design alternatives.

A framework for reasoning



A framework for reasoning



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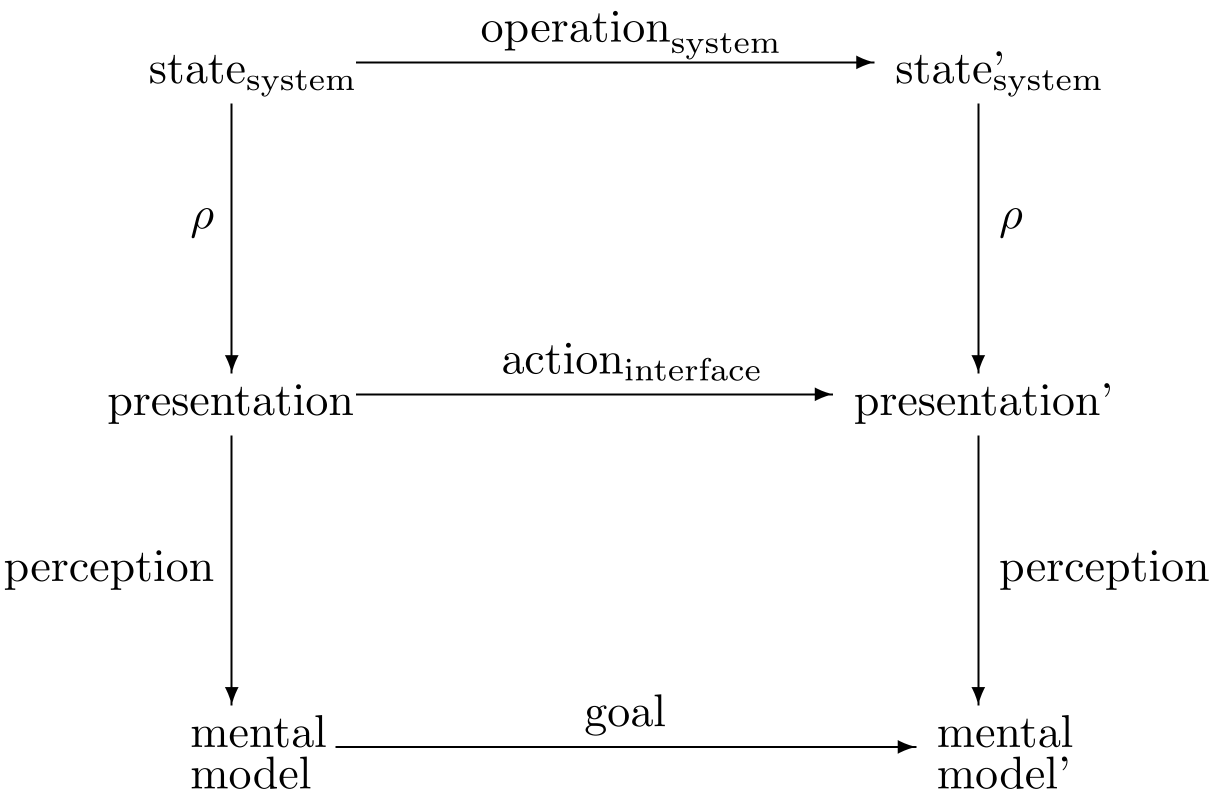
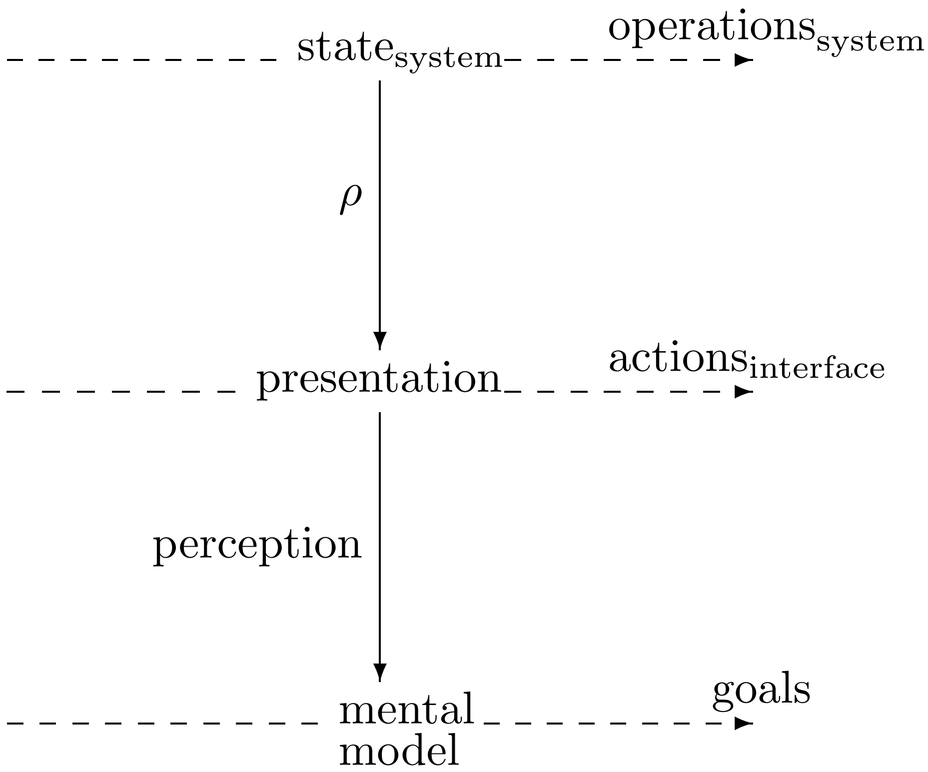
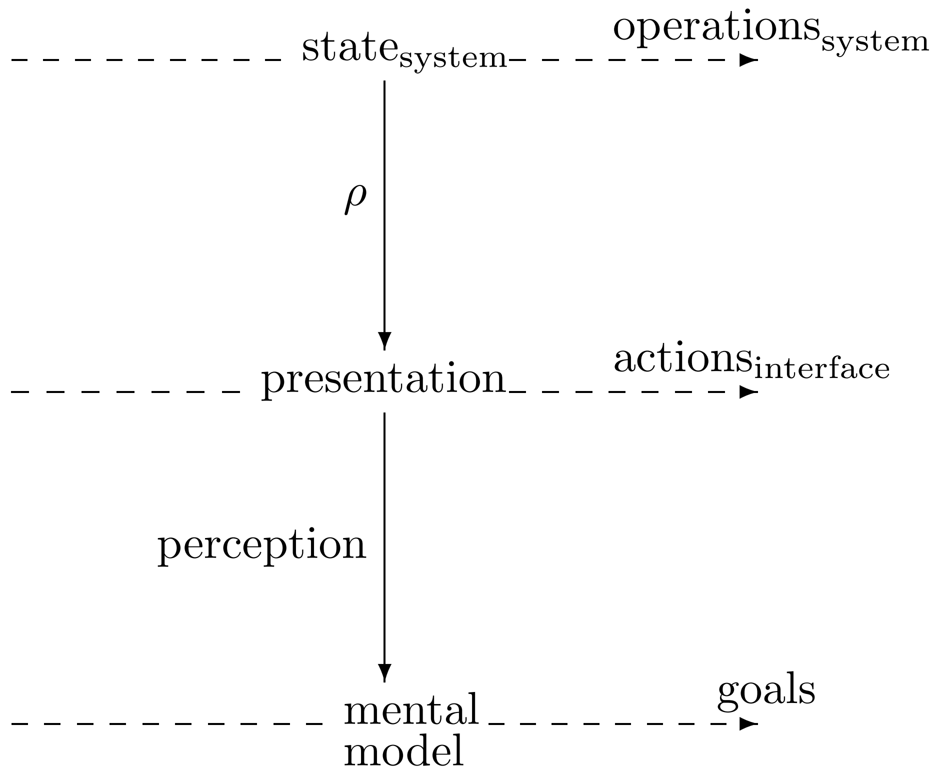


$$\text{interpretation}_{\text{logical}}(\text{System}, \text{operation}(\text{System})) = \text{interpretation}_{\text{mental}}(\text{MentalModel}, \text{goal}(\text{MentalModel})) \quad (1)$$

A framework for reasoning (Time)



A framework for reasoning (Time)



$$\forall_{t_1,t_2} \cdot \text{interpretation}_{\text{logical}}(\text{System}, t_1, t_2) = \text{interpretation}_{\text{mental}}(\text{MentalModel}, t_1, t_2) \quad (2)$$

The Example

We will consider a number of variations on a small dynamic information display which should keep users informed of the progress made during the download of information.

Simple progress bar

System Model/Presentation Model/User's Mental Model

What task?

The Example

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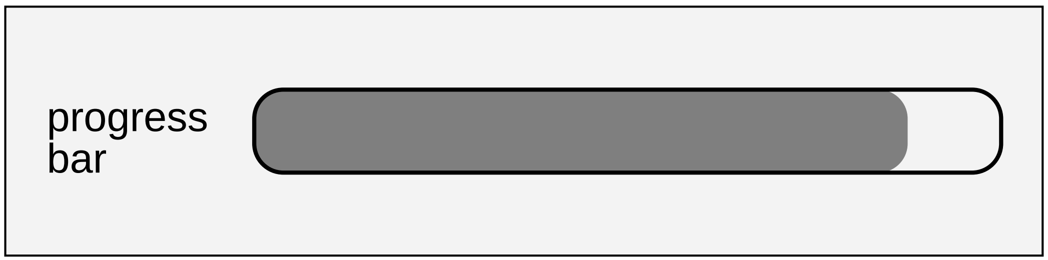

System Model/Presentation Model/User's Mental Model

$$\forall_{t_1,t_2,s} \cdot \mathsf{rate}_{\mathsf{logical}}(s, t_1, t_2) = \mathsf{rate}_{\mathsf{mental}}(\mathsf{perception}(\rho(s)), t_1, t_2)$$

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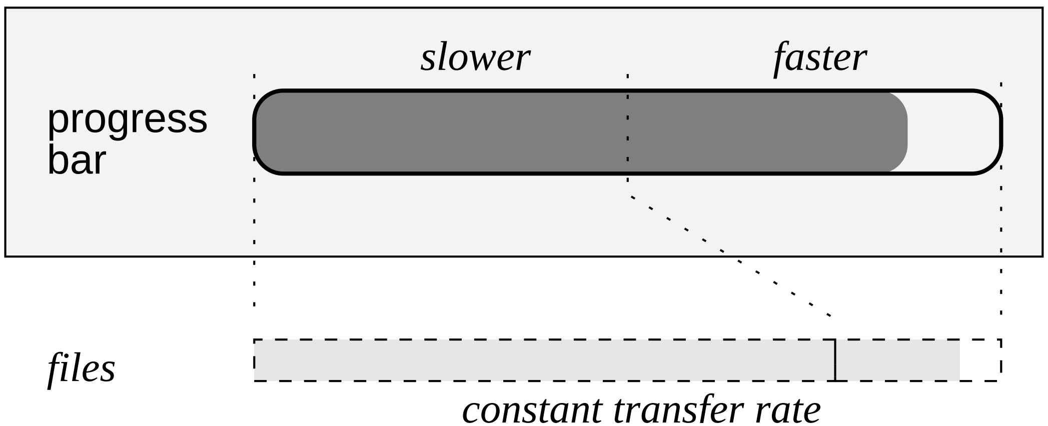
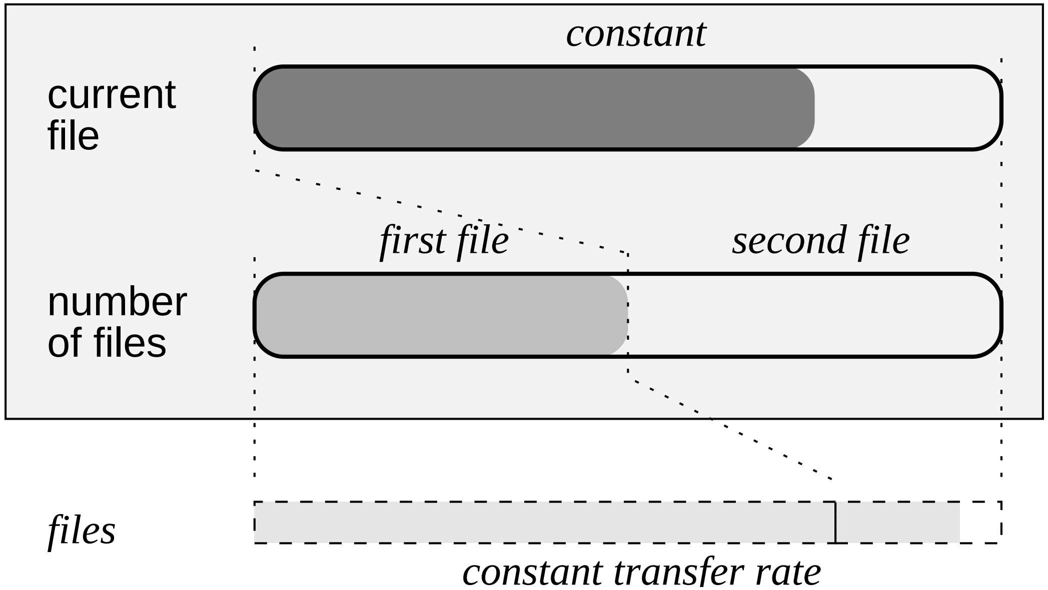


System Model/Presentation Model/User's Mental Model

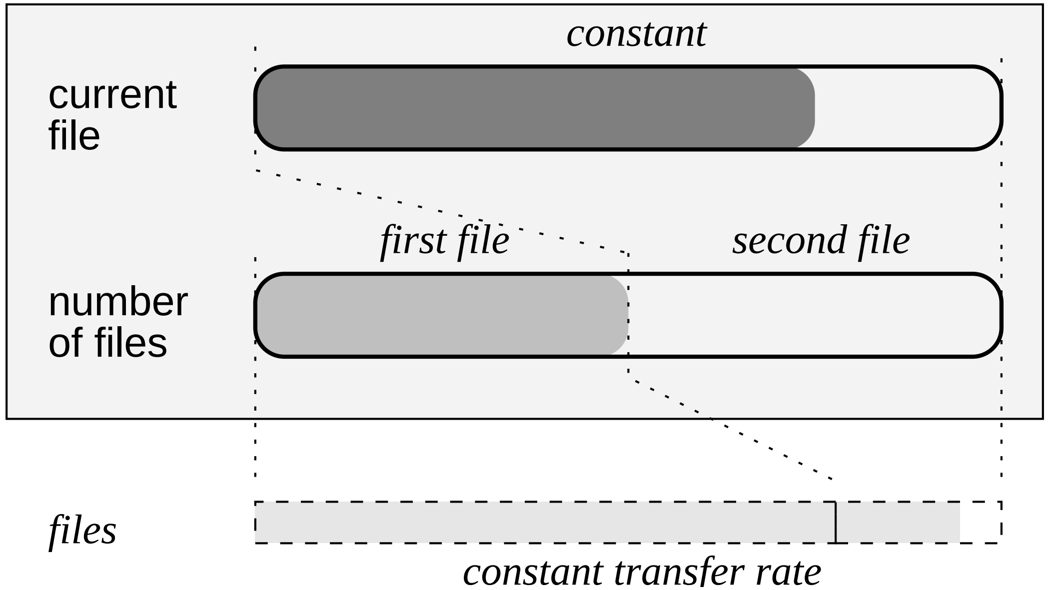
shorter message $\longrightarrow$ faster transfer / longer message $\longrightarrow$ slower transfer

Second alternative



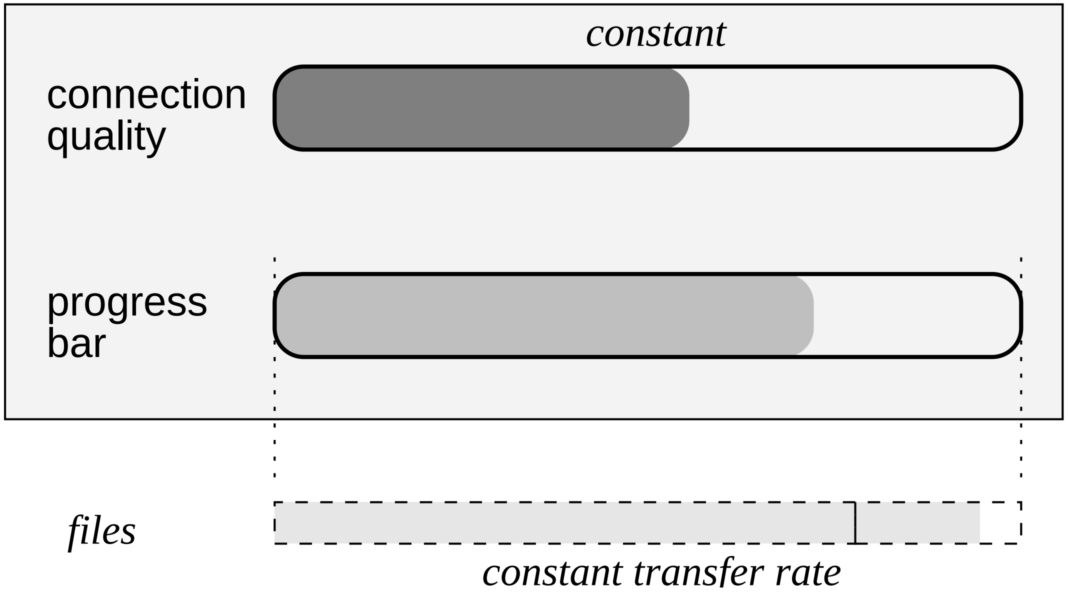
$$\forall_{t_1,t_2,s} \cdot \mathsf{rate}_{\mathsf{logical}}(s, t_1, t_2) = \mathsf{rate}_{\mathsf{mental}}(\mathsf{perception}(\rho(s)), t_1, t_2)$$

Second alternative



- does not support the long term task of looking for higher rates — works on a message by message basis

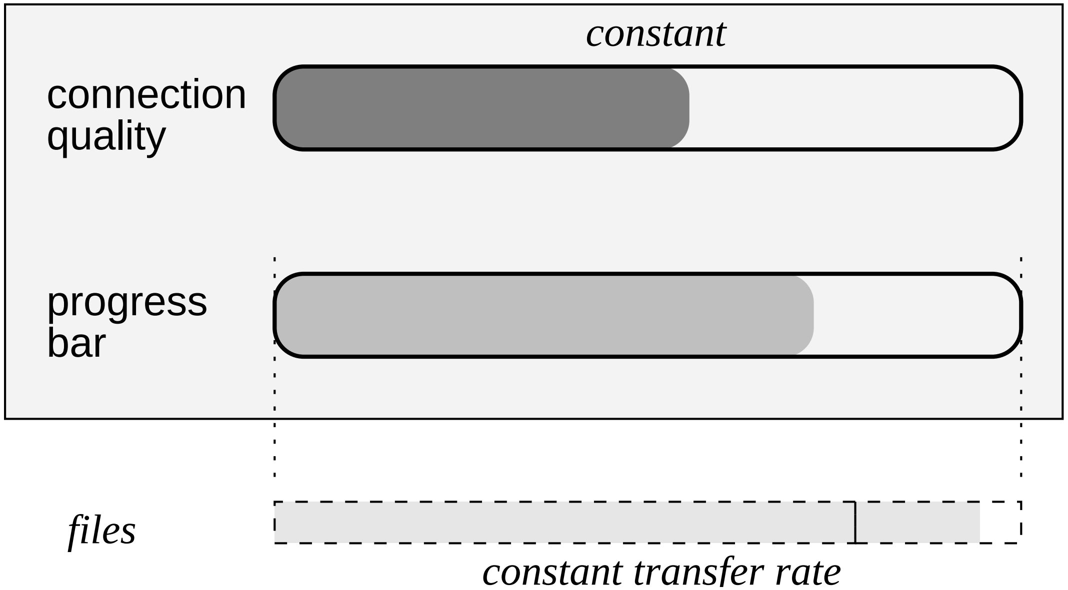
Third alternative



$$\forall_{t,s} \cdot \mathsf{rate}_{\mathsf{logical}}(s,t) = \mathsf{rate}_{\mathsf{mental}}(\mathsf{perception}(\rho(s)),t)$$

$$\forall_{t_1,t_2,s} \cdot \mathsf{rate}\Delta_{\mathsf{logical}}(s,t_1,t_2) = \mathsf{rate}\Delta_{\mathsf{mental}}(\mathsf{perception}(\rho(s)),t_1,t_2)$$

Third alternative



- good indication of instantaneous progress
- good indication of overall progress (**if** changes in connection quality are slow)

Conclusions/Lessons Learned

- The model can be used to reason about representational aspects where time considerations are at stake.
- Using rigorous analysis, it is possible to uncover assumptions concerning interaction and perception, which are implicitly made during the design of the interface.
- Use of rigorous proofs can help in reasoning about design, but designers are not tied to its use.
- The example has shown how considerations about the users' goals, and scenarios of usage, can help in analysing alternative design options.
- All the reasoning was performed in the context of first order propositional logic, this allows use of readily available automated reasoning tools. It also removes a significant barrier to understanding by non-specialists.

References

[DCH00] G. Doherty, J. C. Campos, and M. D. Harrison. Representational reasoning and verification. *Formal Aspects of Computing*, 12:260–277, 2000.

[DH97] Gavin Doherty and Michael D. Harrison. A representational approach to the specification of presentations. In M. D. Harrison and J. C. Torres, editors, *Design, Specification and Verification of Interactive Systems '97*, Springer Computer Science, pages 273–290. Springer-Verlag/Wien, June 1997.

[Hut95] E. Hutchins. How a cockpit remembers its speed. *Cognitive Science*, 19:265–288, 1995.

[UI00] B. Ullmer and H. Ishii. Emerging frameworks for tangible user interfaces. *IBM Systems Journal*, 39(3&4), 2000.

System Model

$$\begin{aligned}
\text{Mesg} : \text{TYPE} = [\#\text{Info} : \text{Data} \\
\text{Size} : \text{Nat}\#]
\end{aligned}$$

$$\begin{aligned}
\text{DL} : \text{TYPE} = [\#\text{Done} : \text{Mesg-list} \\
\text{Current} : \text{Mesg} \times \text{Nat} \\
\text{ToDo} : \text{Mesg-list}\#]
\end{aligned}$$

$$\text{State} : \text{TYPE} = \text{Time} \rightarrow \text{DL}$$

$$\begin{aligned}
&\text{rate}_{\text{logical}}((s : \text{State}), (t_1, t_2 : \text{Time})) : \text{Real} = \\
&\qquad (\text{progress}(s, t_2) - \text{progress}(s, t_1))/(t_2 - t_1)
\end{aligned}$$

$$\text{progress}((s : \text{State}), (t : \text{Time})) : \text{Nat} = \left(\sum_{m \text{ in Done}(s(t))} \text{size}(m) \right) + \pi_2(\text{Current}(s(t)))$$

Simple progress bar

Presentation Model

$$\text{ProgressBar} : \text{TYPE} = [\#\text{Size} : \text{Nat}$$
$$\text{Filled} : \text{Nat}\#]$$
$$\text{Presentation} : \text{TYPE} = \text{Time} \rightarrow \text{ProgressBar}$$

$$\rho((s : \text{State})) : \text{Presentation} = \lambda t : \text{Time},$$
$$(\#\text{pbsize}, \left(\text{len}(\text{Done}(s(t))) + \frac{\pi_2(\text{Current}(s(t)))}{\text{Size}(\pi_1(\text{Current}(s(t))))}\right) \times \frac{\text{pbsize}}{\text{len}(\text{Done}(s(t)))+1+\text{len}(\text{ToDo}(s(t)))}\#)$$

Simple progress bar

User's Mental Model

$$\text{DLp} : \text{TYPE} = [\#\text{Done} : \text{Real}\#]$$

$$\text{MentalModel} : \text{TYPE} = \text{Time} \rightarrow \text{DLp}$$

$$\text{perception}((p : \text{Presentation})) : \text{MentalModel} =$$
$$\lambda t : \text{Time}.(\#\text{Done}(p(t))/\text{Size}(p(t))\#)$$

$$\text{rate}_{\text{mental}}((mm : \text{MentalModel}), (t_1, t_2 : \text{Time})) : \text{Real} =$$
$$(\text{Done}(mm(t_2)) - \text{Done}(mm(t_1)))/(t_2 - t_1)$$

Simple progress bar