Ambient and mobile systems: new challenges for interactive systems analysis

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Ambient and mobile systems

- Bringing information and services to the users of complex built environments, allowing appropriation of the environment for the task at hand
- Success depends on how users *experience* the space in which they are situated, for example a space as a place.
- Problem:
  - How to assess formatively whether the system improves the user's experience
  - How to engineer the system to implement experience requirements

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Structure of the talk

- What are the ingredients of the systems of concern in the talk
- What do we mean by usability and what are the problems with capturing and assessing usability requirements
- Using formal techniques to assess usability

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HURSTBRIDGE
2:50 9 3
ELTHAM
3:10 9
GLEN WAVERLEY
2:53 10
HURSTBRIDGE
EPPING
LILYDALE
BELGRAVE
ALAMIEN
PAKENHAM
2:54 12
CRANBOURNE
3:06 12
FRANKSTON
FRANKSTON
TAKE NEXT
TRAIN TO
FLINDERS ST
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WAVERLEY
PAKENHAM
CRANBOURNE
FRANKSTON
SANDRINGHAM
WILLIAMSTOWN
2:59 11 12
WILLIAMS TOWN
SYDENHAM
WERRIBEE
BROADMEADOWS
UPFIELD

Background (interactive system) research challenges

- Techniques and paradigms for interaction in built environments, for example
  - Relating public and private display
  - Dynamic displays
  - Local and relevant information
- Middleware infrastructures, services deployed according to context
  - Aura (Garlan et al), broker uses context information
  - Trail (Clarke et al), representation of context as history

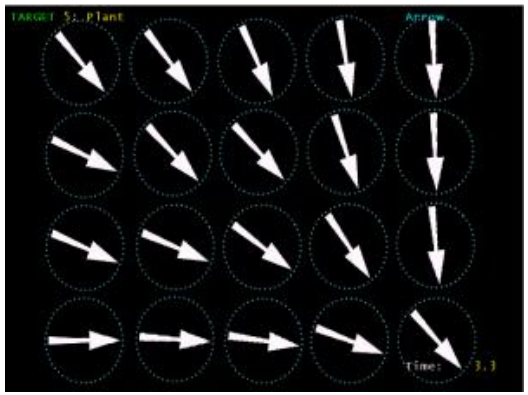
CrossFlow (Cao and Olivier) -- an indoor navigation system

Personal mobile device

haptic information (rhythmic vibration)

User: indoor pedestrian

Mapping: time-multiplexing



visual information: direction (projected animation)

Public ambient displays system

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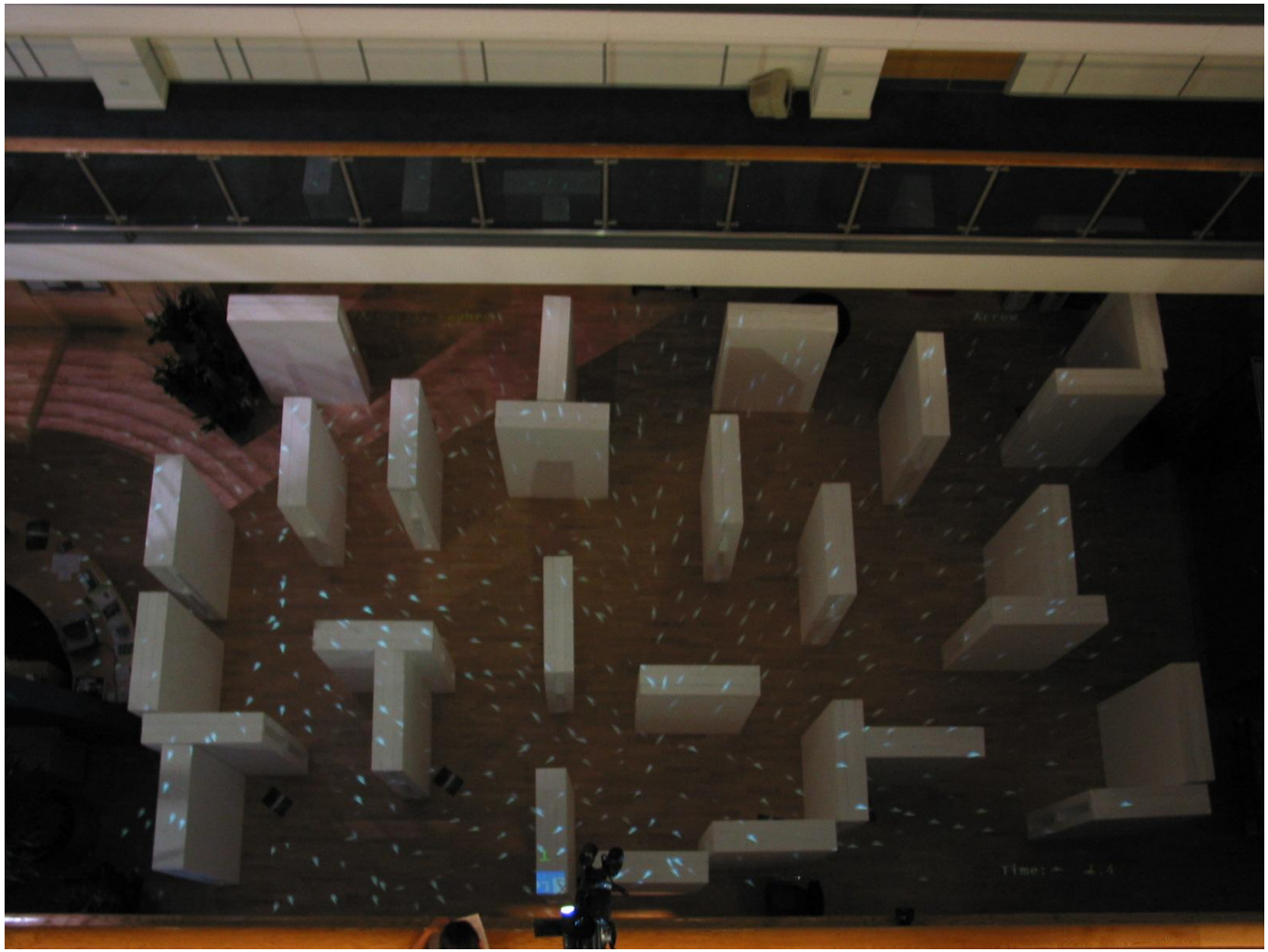
Crossflow and the maze



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Dynamic displays (Chris Kray)

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Aura middleware (Garlan et al.)

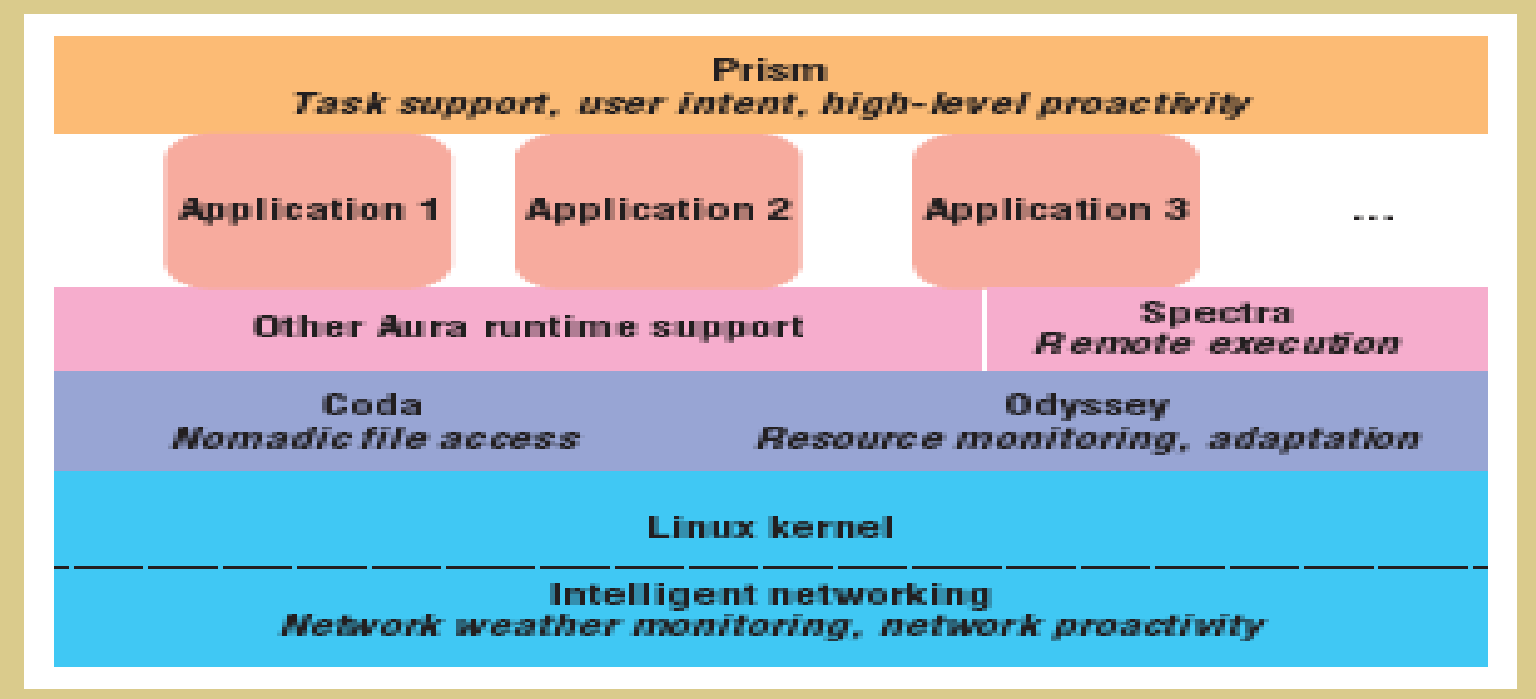
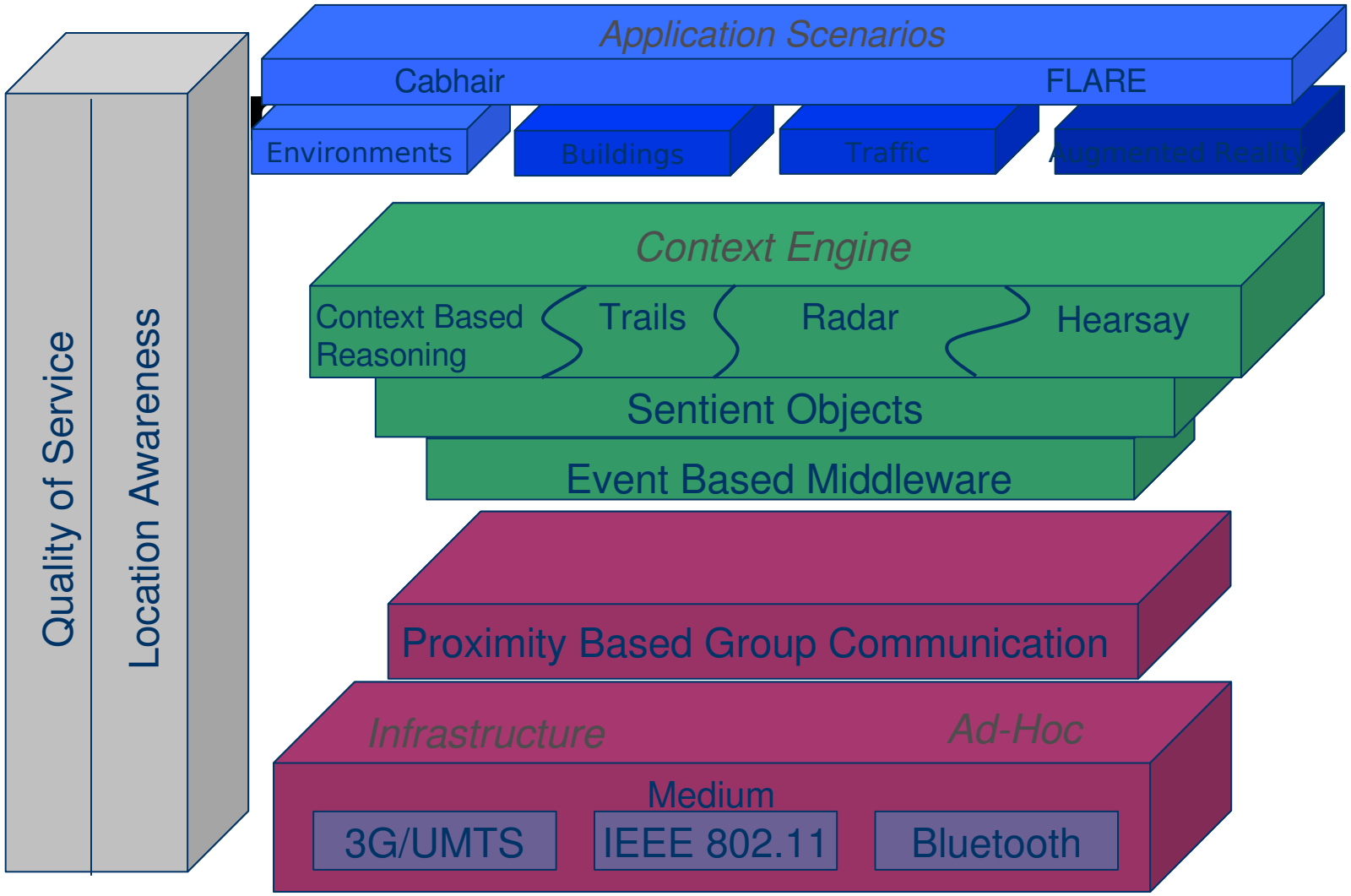


Figure 1. The Aura architecture.

Hermes (Clarke and Driver)



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Trail

- Describes what the user has done – actions, locations etc
- Can be used as a basis for inference or can be used to drive the activity – the dynamic displays
- Trails are like work flows used in business processing or bio-informatics (used as first class objects)

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But many interactions are possible

- Notifying of the availability of services when flights are delayed
- Allowing seat reservation and automated check-in, including response to security questions
- Automated scanning and identification
- Rerouting, automatic hotel booking and complimentary meal tickets when flights delayed
- Explanations of the reasons for the delay and the steps that are being taken to rectify the situation
- Some are already part of life – providing a “joined up” service environment

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How do you evaluate usability of such systems

- Traditional notions of usability are important – interactive behaviour of devices
- But also need to take account of the environment and the experience of the user within the environment
  - Experience as a place or a space
  - Alleviate the experience of anxiety in an unfamiliar and threatening environment
  - Making the whole process from check-in to collecting baggage and travelling into the city seem to be joined up
  - Experience design already a part of service design in retail outlets for example
- See “Technology as Experience” John McCarthy and Peter Wright. MIT Press

For such evaluation in built environments

- The environment is a major contributor to understanding how the system should work, its texture and complexity
- It is difficult to assess the experience of ambient and mobile systems early in the design process when the target environment is not available, without considerable expense and substantial design commitment.
- Scenarios provide some help but more is required
- *How might we explore experience requirements in the early stages?*

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Typical system: airport

- When the passenger enters a new location, the sensor detects the passenger's presence. The next message received concerns flight information and updates the passenger's handheld device with information relevant to the passenger's position and stage in the embarkation process.
- When the passenger moves into a new location then if the passenger is the first from that flight to enter that location, then public displays in the location are updated to include relevant flight information.
- When the last passenger in the location on a particular flight leaves it then the public display is updated to remove this flight information.
- As soon as a check-in queue sensor receives information about a passenger entering a queue then queue information on the public display will be updated.
- While in the queue, passenger invited to select a seat via hand-held.

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Analysing experience

- Shift away from understanding the use of artefacts to understanding their presence in people's lives
  - Halnass and Redstrom (2002) From use to presence: on the expressions and aesthetics of everyday computational things. ACM Transactions on Computer Interaction 9(2): 106-124.
- User centred design helps understand the practices and routines into which technologies are expected to fit, not so useful for dealing with feelings of resistance, engagement, identification, disorientation and dislocation.

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Eliciting and making sense of experience requirements

- stories that capture experience of different personae
  - E.g., experience of technical fault in Amsterdam airport

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Scenario

- Getting on the plane and after an hour being asked to get off
- Plane delayed from 15.00 to 18.30.
- At 17.00 given meal tickets.
- On return 18.00 told the flight had been cancelled.
- Told to proceed to transit desk T2.
- At T2 told to go somewhere else because I had a paper ticket.
- At this desk told to go to the baggage claim desk.
- Given vouchers for a hotel and a free phone call.
- Waited for the bags to arrive and then looked for the shuttle bus…
- The shuttle bus had to be organised specially to collect us at 5.30 the following morning – then no knowledge of us when checking in.
- Too late to put the bag on the conveyer.
- Go to another conveyer.
- Too late.
- Take suitcase as hand luggage through screening.
- I was carrying a pen knife.
- And so it went on.
- At each stage the staff did not know what was happening and had to ring the previous desk to get information.

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Eliciting and making sense of experience requirements

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- stories that capture experience of different personae
  - E.g., experience of technical fault in Amsterdam airport
- "snapshot experiences":
  - "I like to sit where I can see the flight display board"
  - "I need to be sure that the flight display board is up-to-date"
  - "I need to know why there is a delay to check whether the predicted delay is credible"

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There are problems with this approach

- How do we help users to explore these scenarios more fully in the context of a proposed design
  - will their imaginations and memories be enough?
  - Will the details of the design be adequately described?
- How do snapshot requirements fit into this environment?

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Visualising scenarios

- Two possibilities
  - Immersive video (Olivier, Kray, Singh at Newcastle)
  - VR simulation of the 3 D world

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Immersive Video

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Immersive video

- Combining video effects with virtual sensors and linked to hand held device, so ambient noise and movement of people etc.
- Video effects could include the superimposition of a public display
- Evaluation of users as they explore filmed scenarios

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Physical reality (Huqiu Zhang)

DESTINATION	TIMETABLE	EXPECTED	OPERATOR
Manchester Airport	11:08	Starts here	First TransPennine Express
London Kings Cross	11:30	Starts here	GNER
Edinburgh	11:40	On time	Virgin Trains
Penzance via Leeds	11:40	11:55	Virgin Trains
London Kings Cross	11:57	11:58	GNER
Glasgow Central	12:05	On time	GNER
Manchester Airport	12:08	Starts here	First TransPennine Express
Plymouth via Doncaster	12:19	Starts here	Virgin Trains
London Kings Cross	12:34	On time	GNER
Bournemouth via Leeds	12:40	No report	Virgin Trains

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Departure Flight
Time Flights Destination
09:30 LH 4711 Copenhagen - Frankfirt
09:45 LG 070 Luxembourg
09:50 AF 741 Paris
10:20 AZ 6872 Roma - Milano
10:45 BA 362 London

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Virtual reality (Zhiyu Sun)

- Creating a world model to replicate the airport with the proposed public displays
  - User steers through the virtual world
  - Physical mobile device and virtual sensors
- The subject can be asked to achieve goals or to re-enact circumstances, no prescribed scenario
- Problems here:
  - lack of ambient realism, people and sound
  - navigation mechanisms may lead to nausea

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Requirements

- Middleware that is interoperable between real and virtual environments
- Explore scenarios in the virtual environment
  - Either as scenarios or as goals to be achieved
  - Using artificial mechanisms to navigate within the virtual space

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Creating scenarios out of snapshots

- Snapshot requirements may be converted into properties of the system
- Specify the system
  - Explored use of uppaal but could use language that captures characteristics of location and mobility (KLAIM)
- Checking properties of the specification using model checker
- Domain experts / human factors experts generate narratives based on interesting traces (counter-examples to the properties)
- Narratives used as a basis for exploration using walkthrough techniques: visualising the scenarios, using personae

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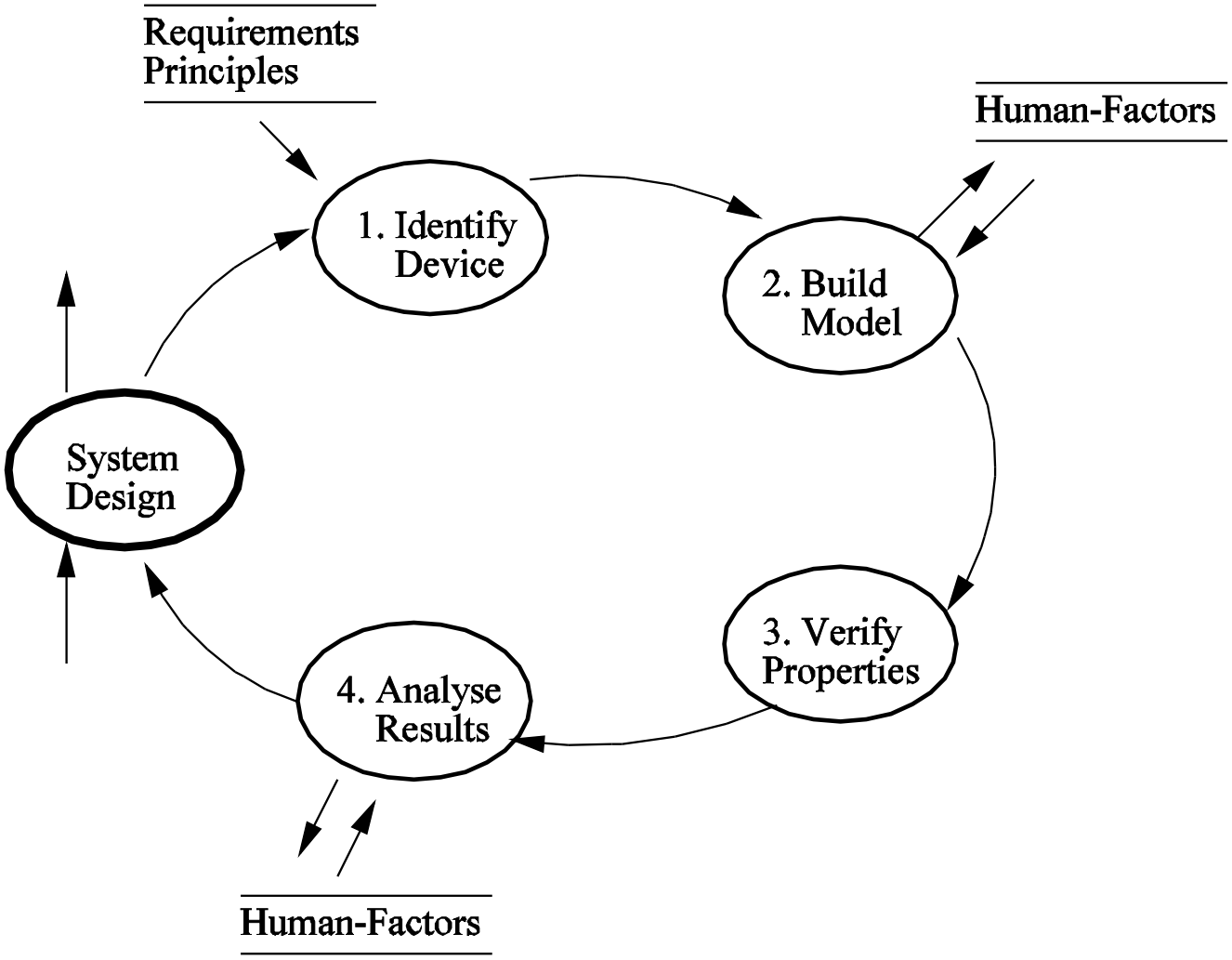
Modelling process (Campos & Harrison)



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Properties based on snapshots

- "I need to be sure that the flight display board is up-to-date"

- when the passenger moves into the location then flight status information is presented to the passenger's hand-held device within 30 seconds
- information on public displays should reflect the current state of the system within a time granularity of 30 seconds

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What to do with these properties?

- About providing the right information, in the right place at the right time
- Failure to adhere to properties does not mean that the system does not perform correctly but will provide counter-examples
- These counter-examples can be used to generate scenarios that can be explored using the visualisation techniques discussed

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Modelling process

- Capture the airport system
- Characterise properties of the airport system – using snapshots to produce properties
- Find sequences where the properties are not satisfied
- Use domain knowledge and human factors expertise to create scenarios – narratives – based on the sequences
- Evaluate the narratives

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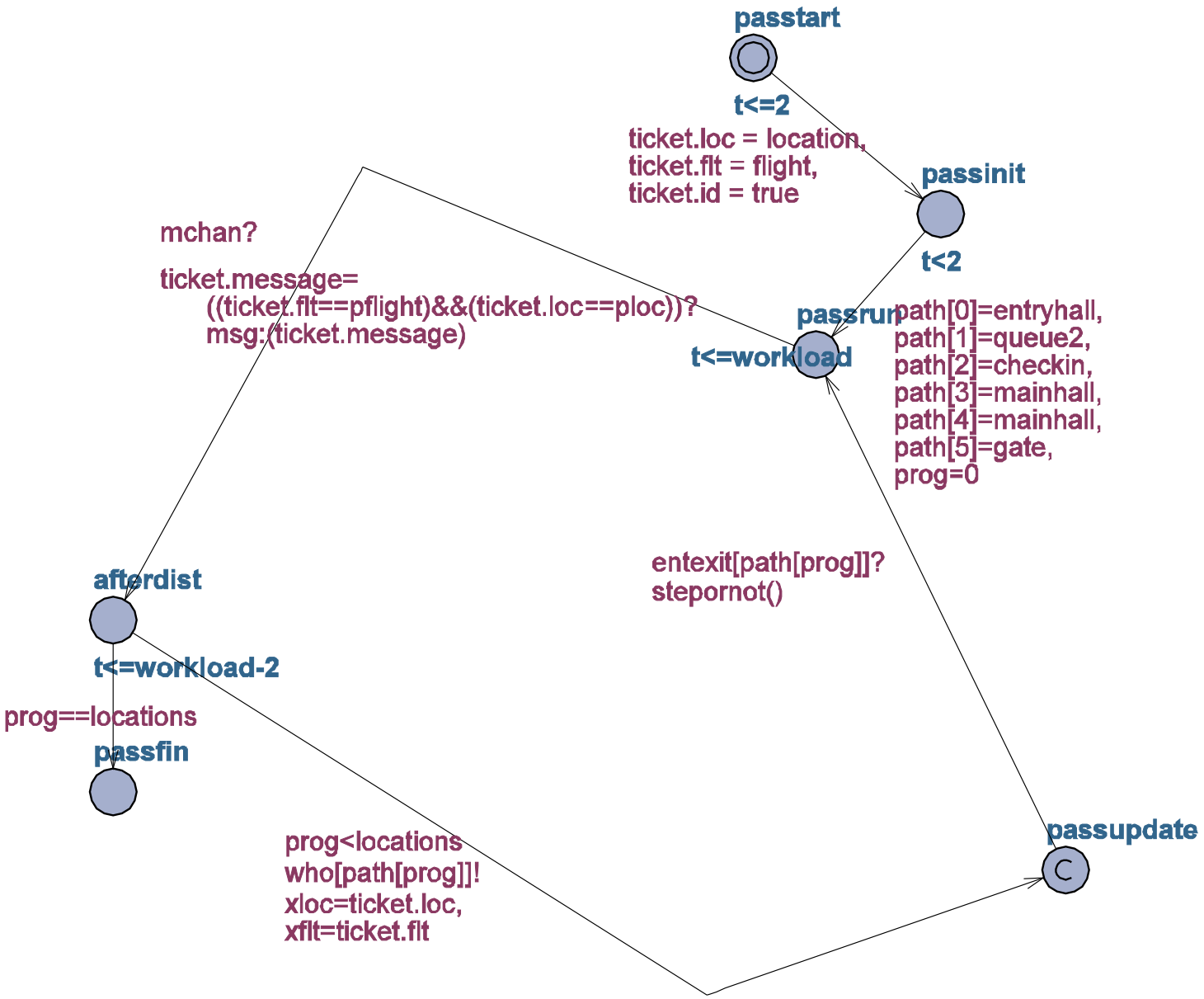
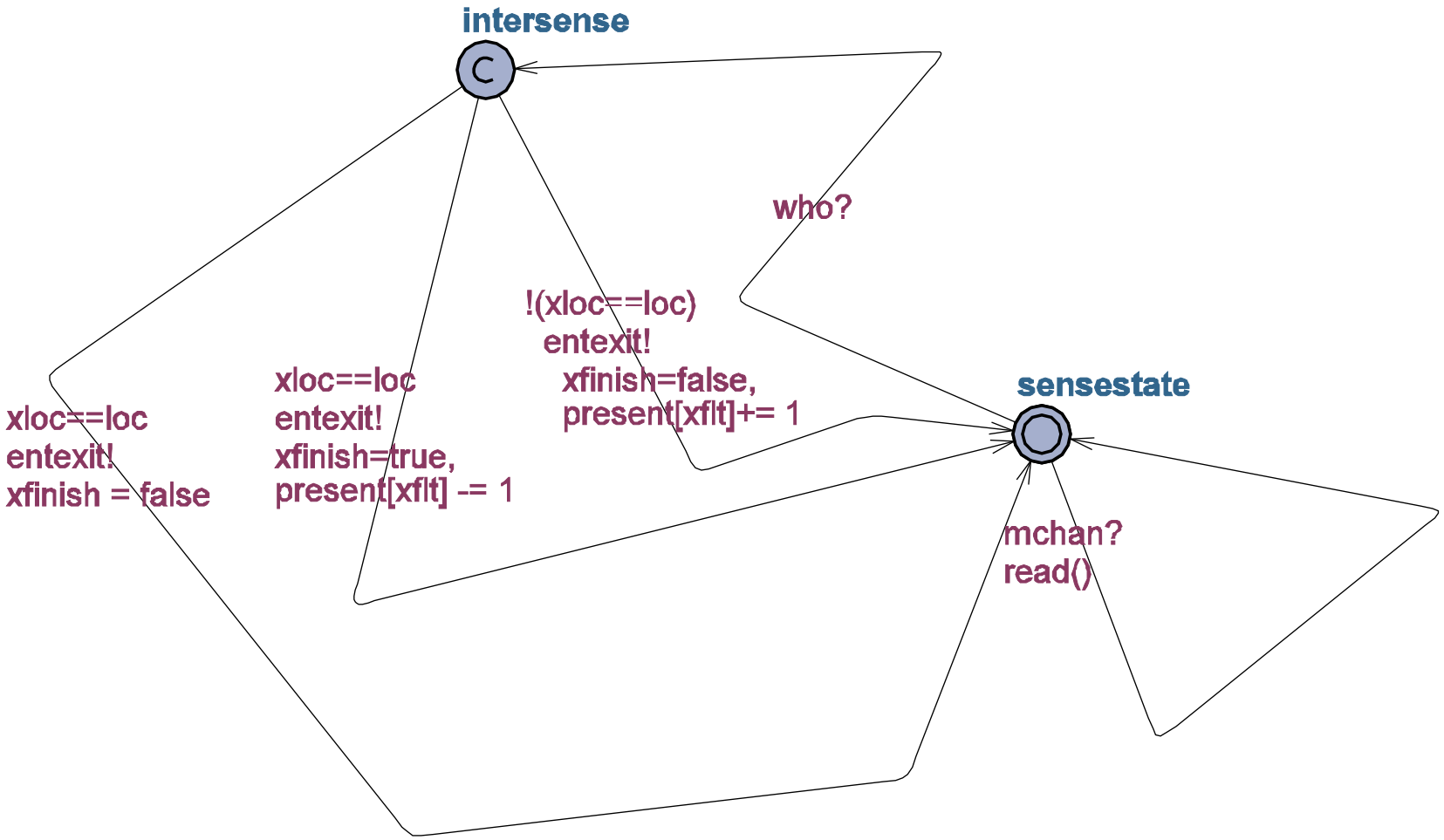
Modelling the passenger



Modelling the sensor



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Examples

- no matter how many services a user is subscribed to, the flight information service will be dispatched both to the user's device and to the local display within a defined time interval
- any service that is offered to a subscriber will only be offered if there is a high probability that there is enough time to do something about the service
- when the passenger moves into the location then flight status information is presented to the passenger's hand-held device within 30 seconds
- information on public displays should reflect the current state of the system within a time granularity of 30 seconds
- if the passenger enters a location then the passenger's trail will be updated with the action that should occur at that stage (for example screening hand baggage) within an appropriate time (two minutes). If not a reminder of the current activity will be delivered to the user's hand-held
- information relating to the best queue to join for a specific flight will be designed to avoid jitter. It will be updated sufficiently frequently to improve the experience of passengers but not so frequently that it will be annoying to passengers.

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Property checking

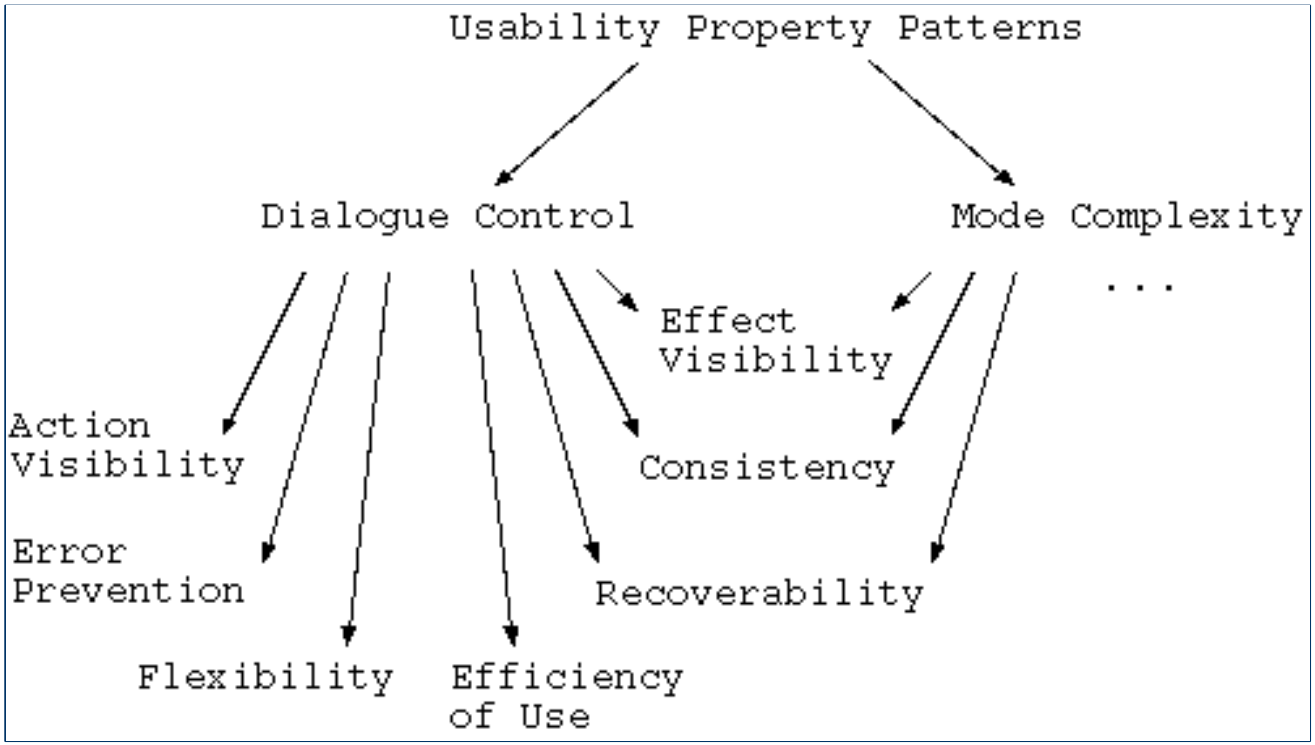
- Exhaustive behavioural usability analysis of interactive systems
  - moding, visibility, recoverability, consistency, predictability, timeliness of information delivery
- Analysis typically performed by usability experts

- In dependable systems domain often formal analysis of
  - system-theoretic properties: e.g. stability/continuity, robustness
  - dynamic temporal properties: safety, liveness, timing
- Analysis performed by formal methods experts

- several issues are *related*, e.g. recoverability and robustness

Templates for Temporal Logic properties

- Dwyer's templates can also be addressed from a usability point of view:



- Based on such templates a CTL property editor can be developed

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```
/* Query */

AG(playing_state=CD_IDLE)&
AF(~PLAY_SIGNAL) -> (~EF
(playing_state=CD_PLAY))

/* state 1 */
CTRL_MECH.state          = OFF,
CTRL_MECH.playing_state  = INACTIVE,
CTRL_MECH.CD_MODE        = 0,
USER.pressONOFF_Button   = 1,
CTRL_ELEM.ONOFF_SIGNAL   = 1,
USER.pressPAUSE_Button   = 0,
CTRL_ELEM.PAUSE_SIGNAL   = 0,
USER.pressPLAT_Button    = 0,
CTRL_ELEM.PLAY_SIGNAL    = 0,
DISPLAYS.AUDIO_state     = QUIET,
[...]

/* state 4 */
CTRL_MECH.state          = ON,
CTRL_MECH.playing_state  = CD_IDLE,
CTRL_MECH.CD_MODE        = 1,
USER.pressPAUSE_Button   = 1,
CTRL_ELEM.PAUSE_SIGNAL   = 1,
USER.pressPLAT_Button    = 0,
CTRL_ELEM.PLAY_SIGNAL    = 0,
DISPLAYS.AUDIO_state     = QUIET,
[...]
/* state 5 */
CTRL_MECH.state          = OFF,
CTRL_MECH.playing_state  = INACTIVE,
USER.pressPAUSE_Button   = 1,
CTRL_ELEM.PAUSE_SIGNAL   = 1,
USER.pressPLAT_Button    = 0,
CTRL_ELEM.PLAY_SIGNAL    = 0,
DISPLAYS.AUDIO_state     = QUIET,
[...]
/* state 6 */
CTRL_MECH.state          = OFF,
CTRL_MECH.playing_state  = INACTIVE,
USER.pressPAUSE_Button   = 1,
CTRL_ELEM.PAUSE_SIGNAL   = 0,
USER.pressPLAT_Button    = 0,
CTRL_ELEM.PLAY_SIGNAL    = 0,
DISPLAYS.AUDIO_state     = MUSIC,
[...]
```

- Counter example
  - Can traces point to interaction problems?
  - Traces contain information about:
    - all system states that are relevant
    - users involved
    - environmental factors
- Traces can be quite long and hard to read
- Traces provide the triggers for generating scenarios

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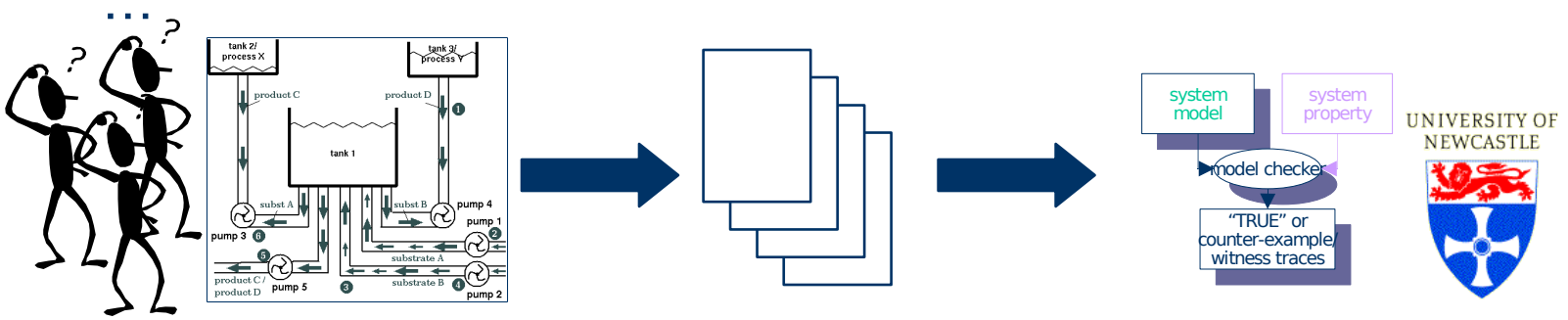
Analysis: Model validity

Experience properties relating to remembering action?

Does the model behave as intended?

- "sanity": deadlock-freedom, state/event reachability
- "goal reachability":
  - Can product C be produced?
  - What is the easiest way to produce product C?
  - What is the "best" way to produce C under assumptions $a_1 \ldots a_n$?
  - Is it possible to reach unsafe states?



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Properties

Property converts to:

SAN1: F (PUMP5CTRLM.state=PMP5ON) & (TANK1.state = HOLDS_C)

Require instances that satisfy property so negate property

- Analyse differences between the control room and the hand-held device (a) and (b).
- Led to conclusion that user might forget to save the controls
- To explore this possibility in extreme add an assumption to the property:
  - assert alwaysForget: G !(savePmp1ctrls| [...] |savePmp5ctrls)
- Exploring this sequence leads to design of interlock mechanism that warns the user and further exploration

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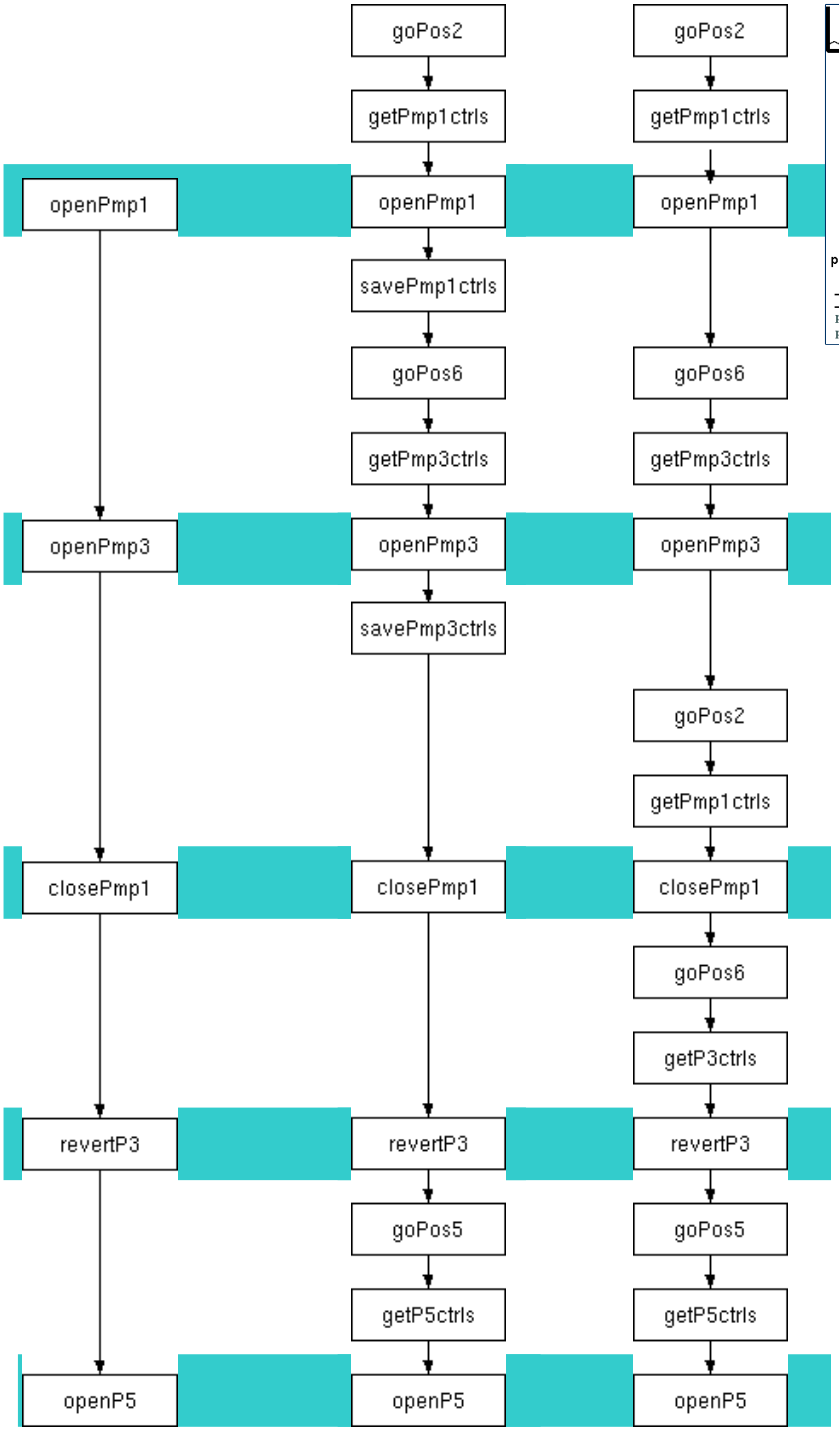
Trace comparison

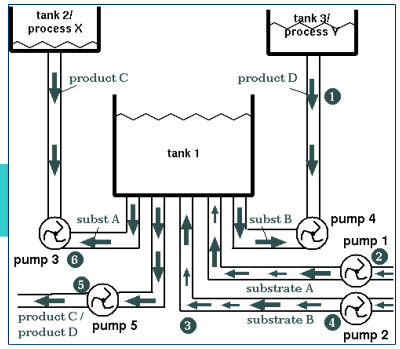
Goal/Property:
"Reachability of a state where end product C is released"

a) Control room interface

b) Mobile device

c) Mobile device (forgetful operator)





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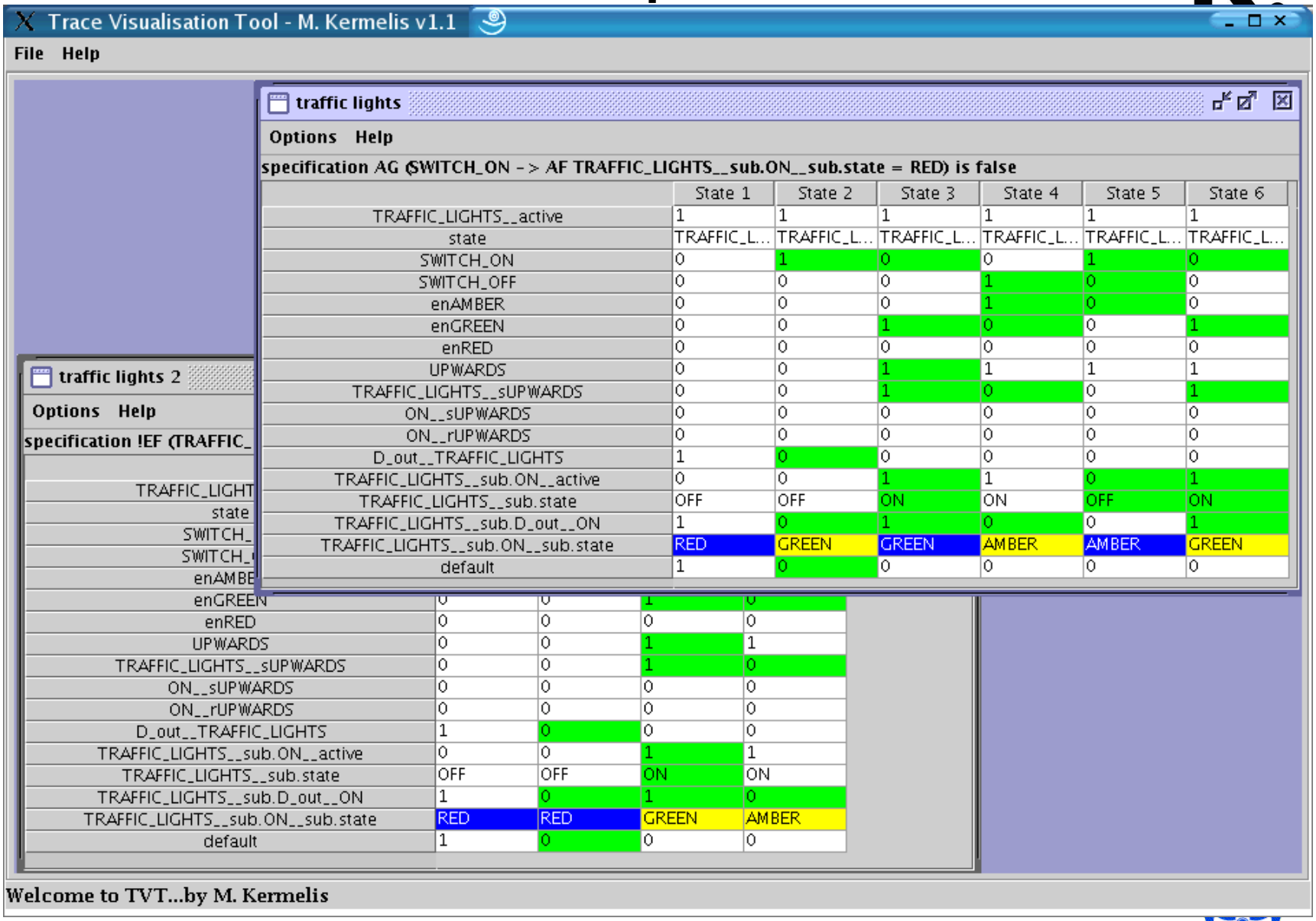
How tool does trace comparison



	State 1	State 2	State 3	State 4	State 5	State 6
TRAFFIC_LIGHTS__active	1	1	1	1	1	1
state	TRAFFIC_L...	TRAFFIC_L...	TRAFFIC_L...	TRAFFIC_L...	TRAFFIC_L...	TRAFFIC_L...
SWITCH_ON	0	1	0	0	1	0
SWITCH_OFF	0	0	0	1	0	0
enAMBER	0	0	0	1	0	0
enGREEN	0	0	1	0	0	1
enRED	0	0	0	0	0	0
UPWARDS	0	0	1	1	1	1
TRAFFIC_LIGHTS__sUPWARDS	0	0	1	0	0	1
ON__sUPWARDS	0	0	0	0	0	0
ON__rUPWARDS	0	0	0	0	0	0
D_out__TRAFFIC_LIGHTS	1	0	0	0	0	0
TRAFFIC_LIGHTS__sub.ON__active	0	0	1	1	0	1
TRAFFIC_LIGHTS__sub.state	OFF	OFF	ON	ON	OFF	ON
TRAFFIC_LIGHTS__sub.D_out__ON	1	0	1	0	0	1
TRAFFIC_LIGHTS__sub.ON__sub.state	RED	GREEN	GREEN	AMBER	AMBER	GREEN
default	1	0	0	0	0	0

TRAFFIC_LIGHT				
state				
SWITCH_				
SWITCH_				
enAMBE				
enGREEN	0	0	1	0
enRED	0	0	0	0
UPWARDS	0	0	1	1
TRAFFIC_LIGHTS__sUPWARDS	0	0	1	0
ON__sUPWARDS	0	0	0	0
ON__rUPWARDS	0	0	0	0
D_out__TRAFFIC_LIGHTS	1	0	0	0
TRAFFIC_LIGHTS__sub.ON__active	0	0	1	1
TRAFFIC_LIGHTS__sub.state	OFF	OFF	ON	ON
TRAFFIC_LIGHTS__sub.D_out__ON	1	0	1	0
TRAFFIC_LIGHTS__sub.ON__sub.state	RED	RED	GREEN	AMBER
default	1	0	0	0

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Snapshot scenarios

- Drive the evaluation
- By analysing and comparing alternative traces
- By using immersive video or virtual reality

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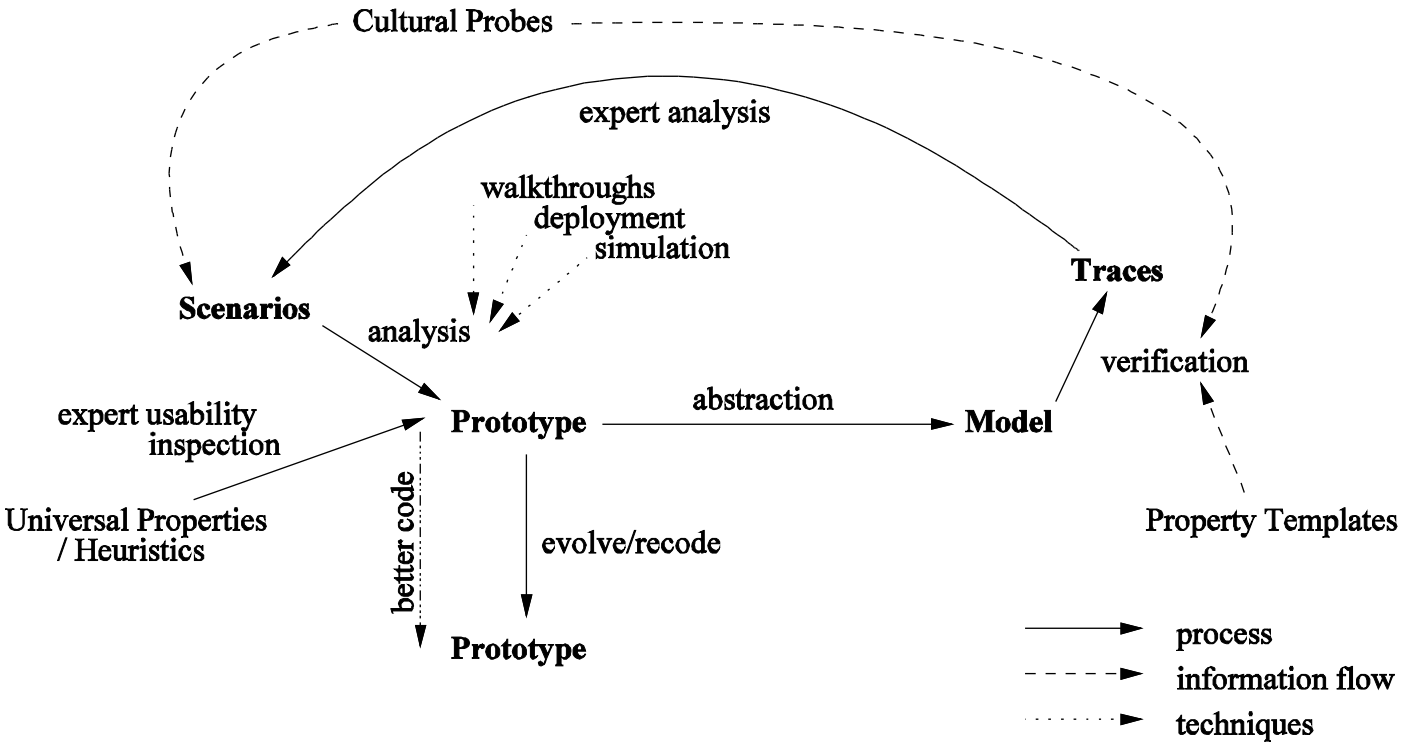
Analysis model



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Summary

- Experience centred design is of particular importance where a user is situated in a dynamic environment involving an ambient and mobile system
- How do you evaluate the design without the target environment?
- Use of virtual techniques
- Perform analysis based on the use of formal methods (currently uppaal and model checking) to identify “interesting” traces relevant to user experience
- Generate narratives based on these traces and explore them through “visualisation” techniques

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