Mental Models and Distributed Cognition

SWE 632
Fall 2015

In class exercise

- Today's question:
- What makes someone an expert?

What makes someone an expert?

Administrivia

- HW1 due in 1 week
- If you have a laptop or tablet, bring it to class

What makes an expert?

What makes an expert?

- Experts are more intelligent?
  - IQ doesn't distinguish best chess players or most successful artists or scientists (Doll & Mayr 1987) (Taylor 1975)
- Experts think faster or have larger memory?
  - World class chess experts don't differ from experts (de Groot 1978)

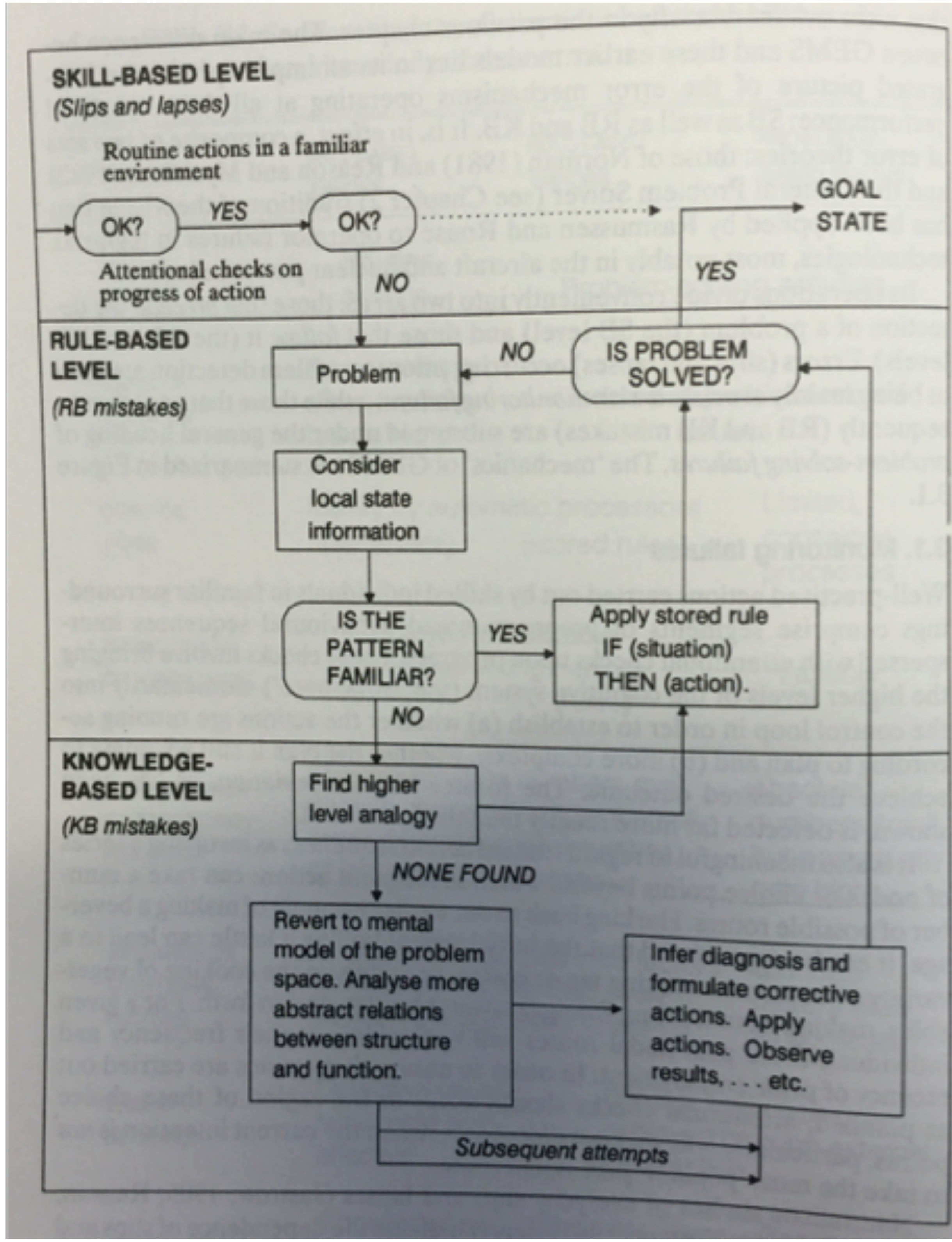
What makes a grand master a chess expert?

- Memory for **random** chess boards: **same** for experts and novices
- Memory for position from **actual** game: much better for **experts** than novices
- [deGroot 1946; Chase & Simon 1973]

Schemas (a.k.a chunking)

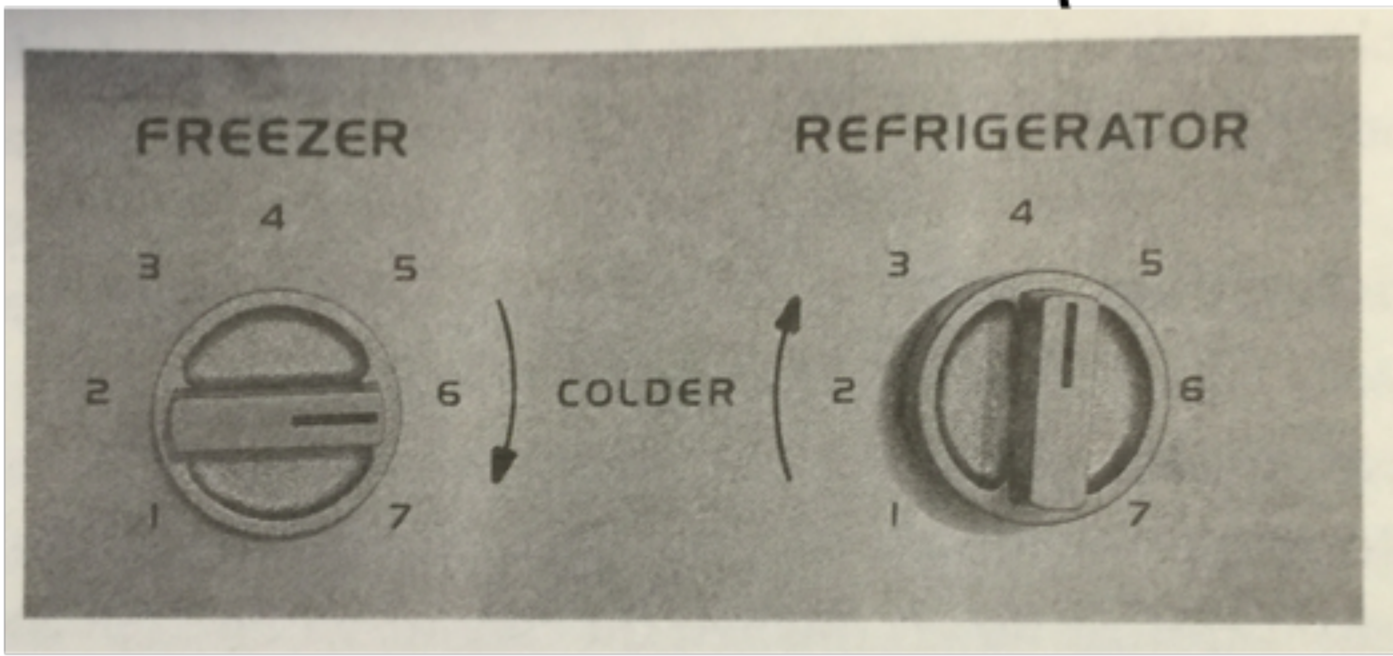
- Experts think differently.
- Have schemas that help them to
  - recognize and react to common situations through System 1
  - encode the world in more abstract terms
  - solve problems more effectively

- Skill / Rule / Knowledge



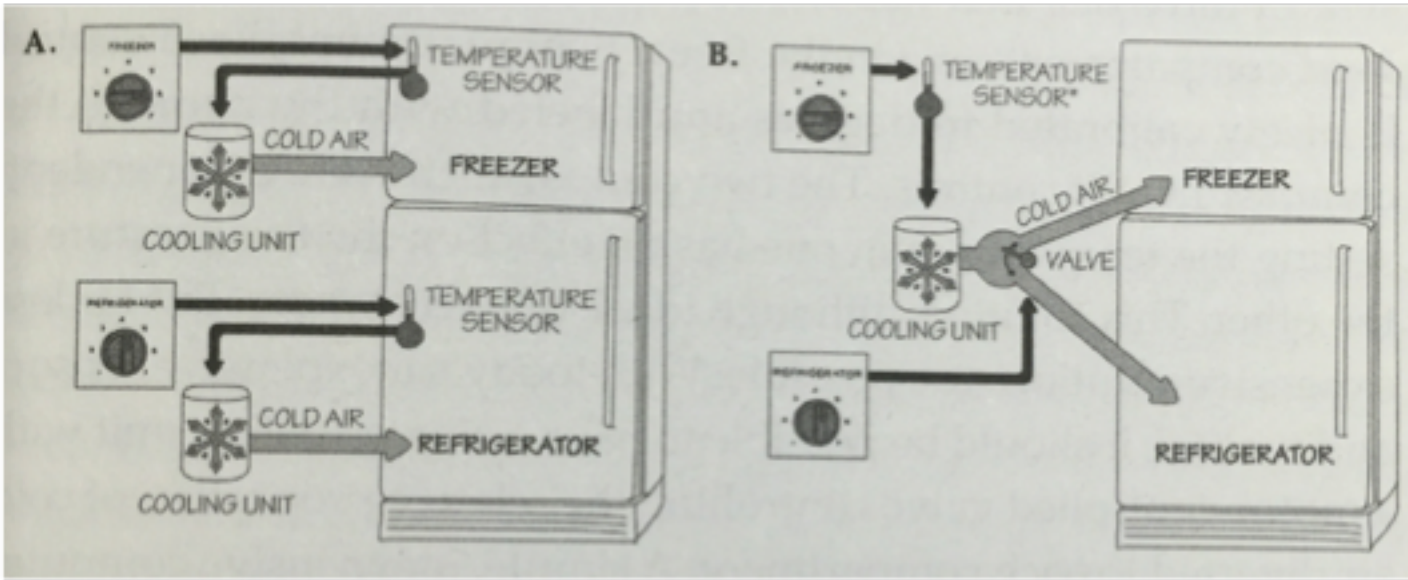
Mental models and problem solving

Mental models (a.k.a conceptual models)



- Internal representation in the head of how something works in the real world
- E.g., changing appropriate knob adjusts temperature in freezer or refrigerator

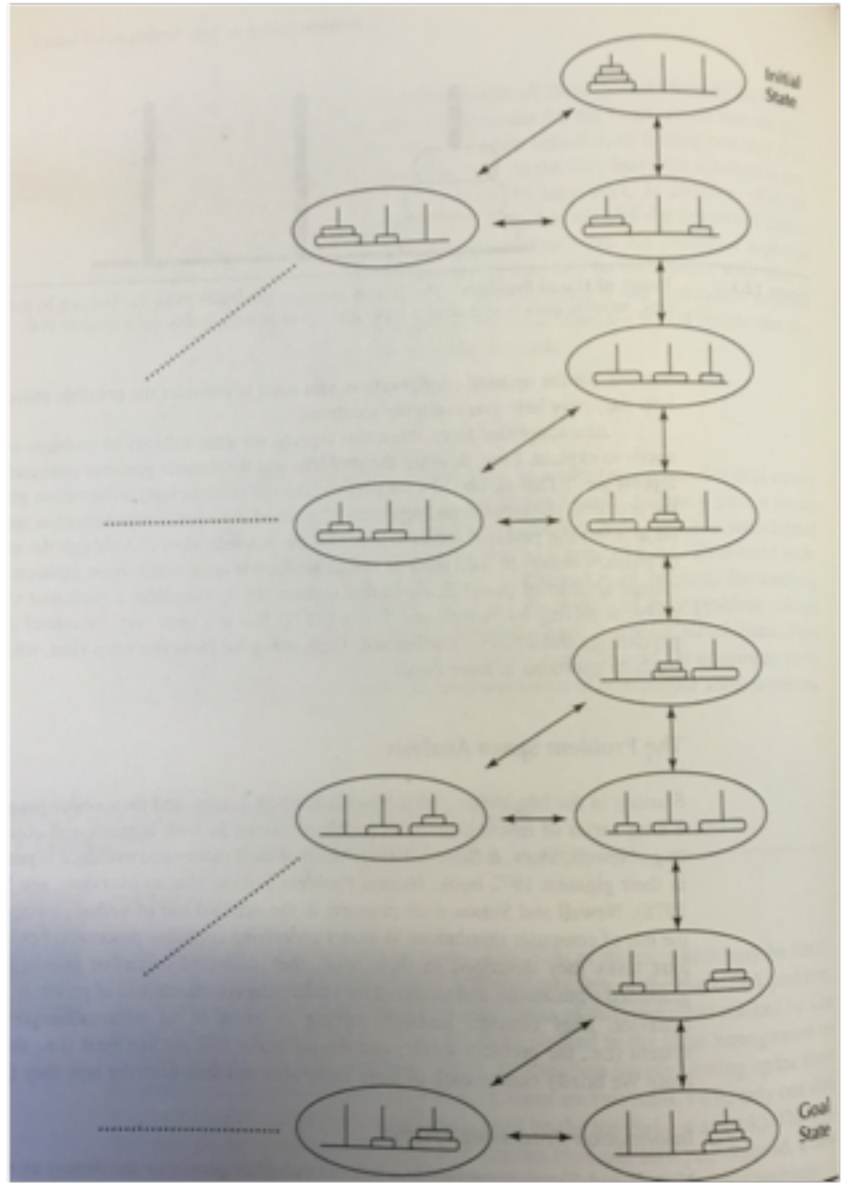
Mental models



- Only single temperature sensor.
- Controls not independent, need to adjust both.
- (also delayed feedback)

Problem solving

- Tower of Hanoi
- Move all the discs from left to right
- No larger disc may be above smaller disc



Problem solving as planning

- Goal state: state of the world to be achieved
- Operators: ways of changing the current state
- Plan: sequence of actions to take to achieve goal

Problem isomorphs

- Problem isomorph - same state space and operators, different presentation
- May be
  - harder to discover operators
  - harder to understand new state
  - harder to represent state
- Problem solving: representation + search

A Monster Move Problem: Isomorph to Tower of Hanoi

Three five-handed extraterrestrial monsters were holding three crystal globes. Because of the quantum-mechanical peculiarities of their neighborhood, both monsters and globes come in exactly three sizes with no others permitted: small, medium, and large. The small monster was holding the large globe, the medium-sized monster was holding the small globe, and the large monster was holding the medium-sized globe. Since this situation offended their keenly developed sense of symmetry, they proceeded to transfer globes from one monster to another so that each monster would have a globe proportionate to its own size.

Monster etiquette complicated the solution of the problem since it requires that:

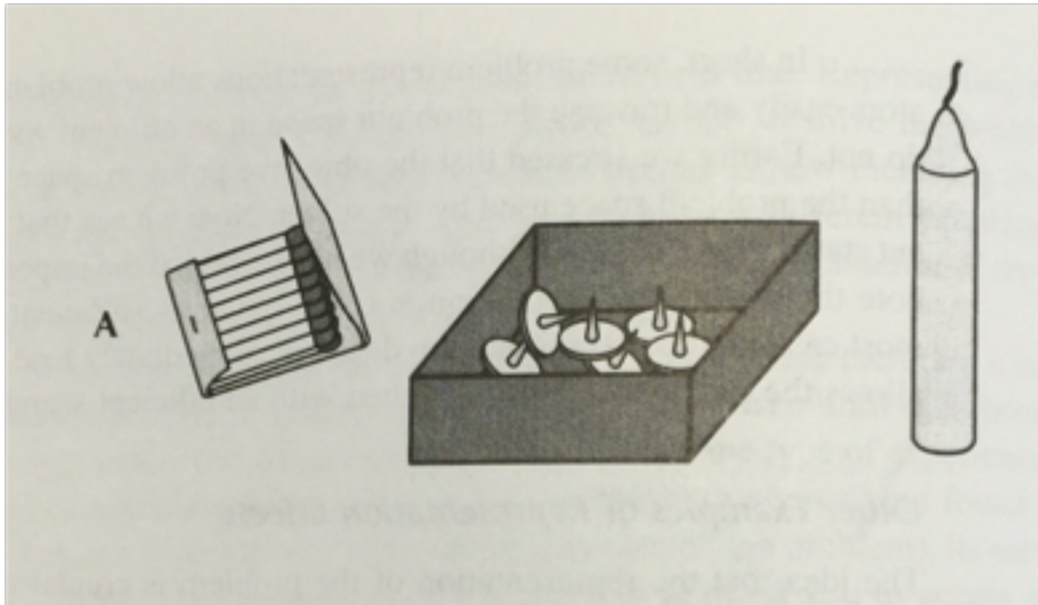
1. Only one globe may be transferred at a time;
2. If a monster is holding two globes, only the larger of the two may be transferred; and,
3. A globe may not be transferred to a monster who is holding a larger globe.

By what sequence of transfers could the monsters have solved this problem?

Source: Kotovsky, Hayes, & Simon, 1985.

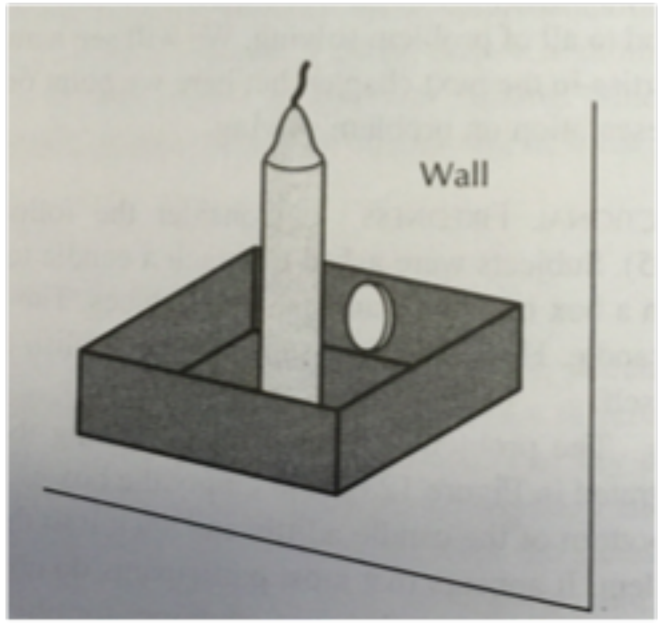
- Isomorph of Tower of Hanoi
- Can take **8x** longer to solve

Duncker's Candle Problem



- Problem: attach a candle to a wall
- Given: box of tacks, candles, matches

Function fixeness



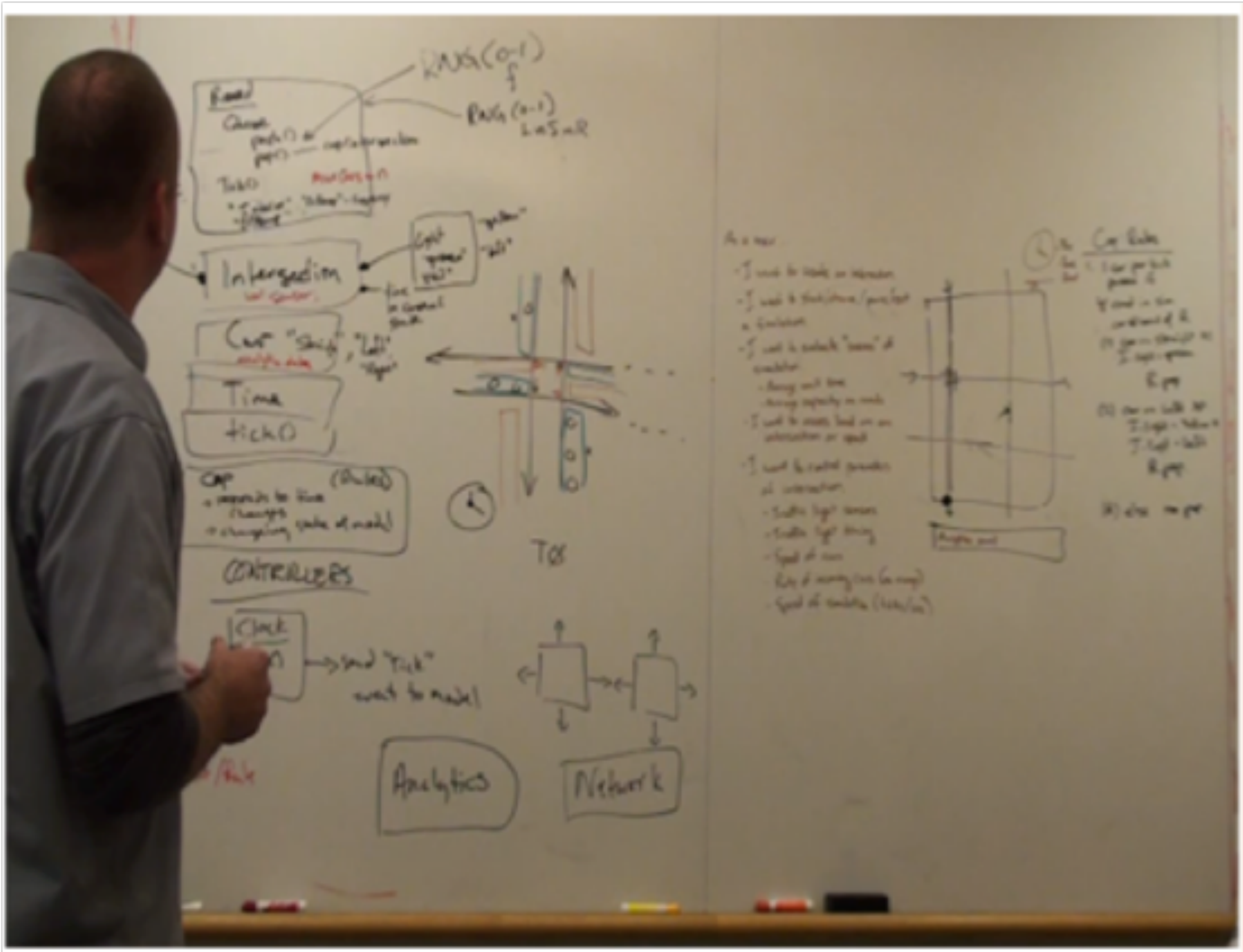
- Solution: tack box to wall, melt candle to stick to box
- Challenge - including box as part of representation
- Functional fixedness: difficulty of seeing full space of operators

Distributed cognition

TABLE 3.1. Tradeoffs Between Knowledge in the World and in the Head

Knowledge in the World	Knowledge in the Head
Information is readily and easily available whenever perceivable.	Material in working memory is readily available. Otherwise considerable search and effort may be required.
Interpretation substitutes for learning. How easy it is to interpret knowledge in the world depends upon the skill of the designer.	Requires learning, which can be considerable. Learning is made easier if there is meaning or structure to the material or if there is a good conceptual model.
Slowed by the need to find and interpret the knowledge.	Can be efficient, especially if so well-learned that it is automated.
Ease of use at first encounter is high.	Ease of use at first encounter is low.
Can be ugly and inelegant, especially if there is a need to maintain a lot of knowledge. This can lead to clutter. Here is where the skills of the graphics and industrial designer play major roles.	Nothing needs to be visible, which gives more freedom to the designer. This leads to cleaner, more pleasing appearance—at the cost of ease of use at first encounter, learning, and remembering.

External representations



External representations

- Reduce STM burden
- Help restructure and reframe problem w/ new abstractions, changing operators
- Encode information and relationships through use of space
- Serve as reminders for future goals

Taking action

Achieving goals

- Goal: make text flow into empty space

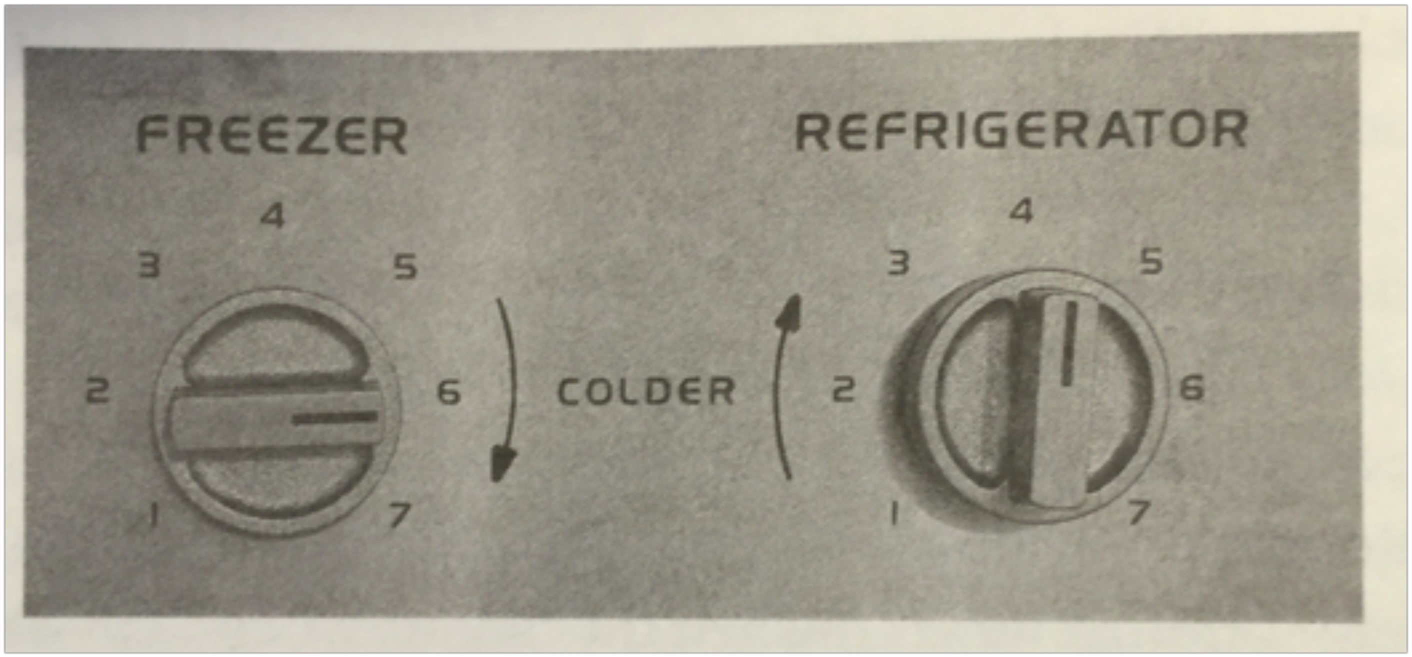
Figure 3. Each pair focused their efforts on a specific aspect of the design.

User-interface-driven User-interface-driven pairs (A, C, G, H) generally asked themselves: "How can users use our system to accomplish their goals?", focusing on front-end sketches and discerning how to get input from the user and display a result. These pairs relied heavily on user interface sketches to structure and organize their work (Figure 3, Figure 3a).

Reflecting the traffic simulator problem domain, the user-interface-driven pairs made frequent use of maps ([illegible] of session time) to brainstorm user interactions and support discussion of the problem. Maps also served as a hub: pairs frequently shifted attention to a map before shifting to a sketch of a different sketch type.

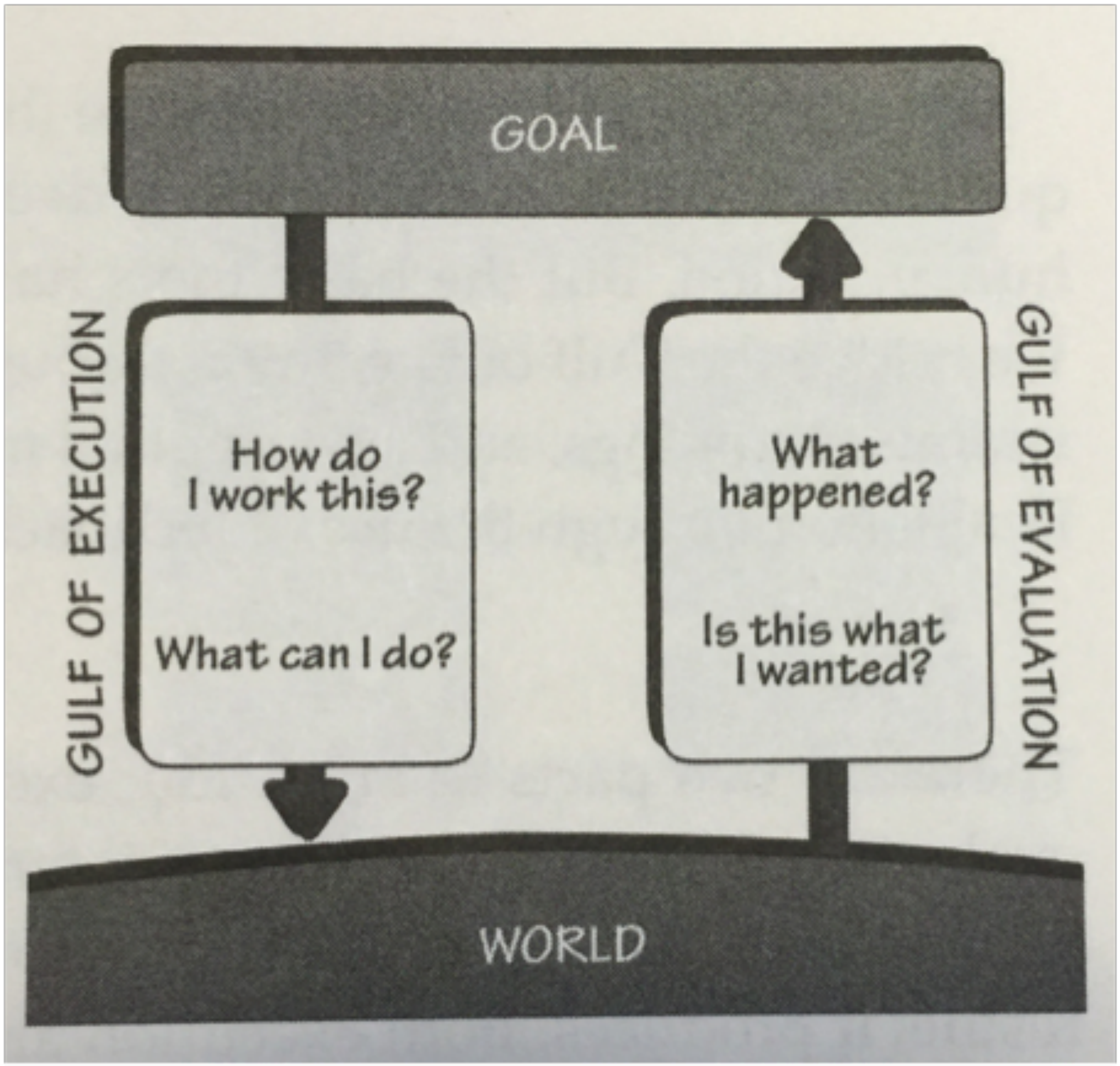
Lists were the second most common sketch type for

Achieving goals



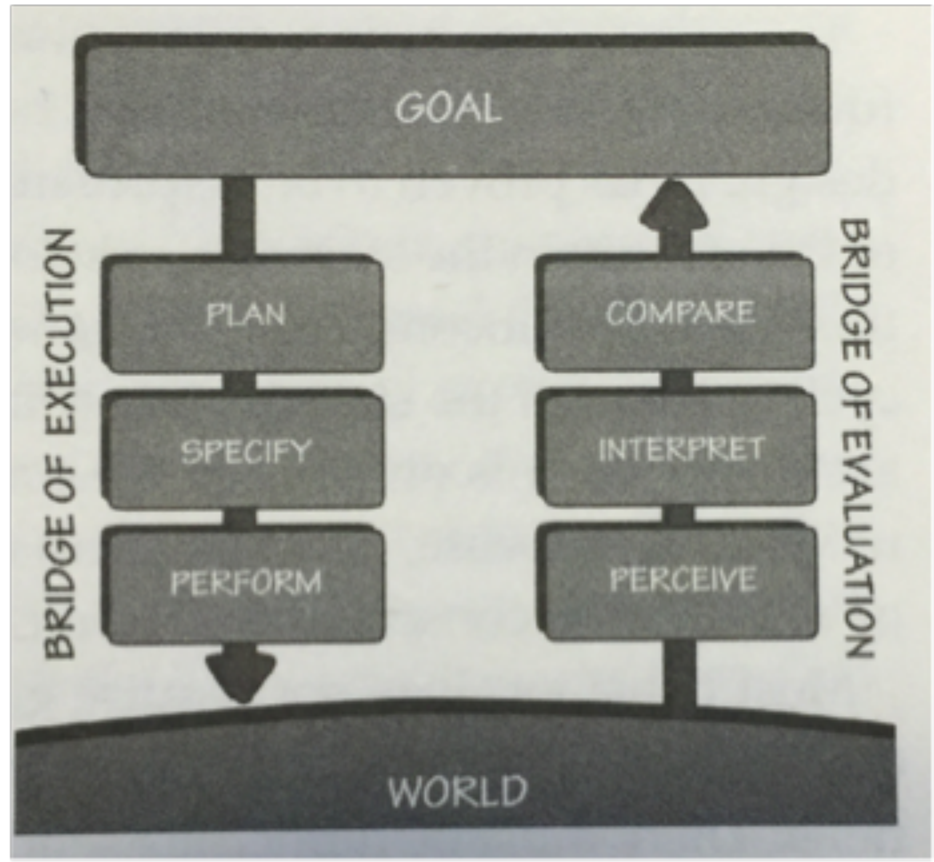
- Turned the refrigerator knob to 4. Will the refrigerator be cold enough now?

Gulfs of execution and evaluation



Norman's 7 stages of action

1. Goal (form the goal)
2. Plan (the action)
3. Specify (action sequence)
4. Perform (action sequence)
5. Perceive (the state of the world)
6. Interpret (the perception)
7. Compare (outcome w/ goal)



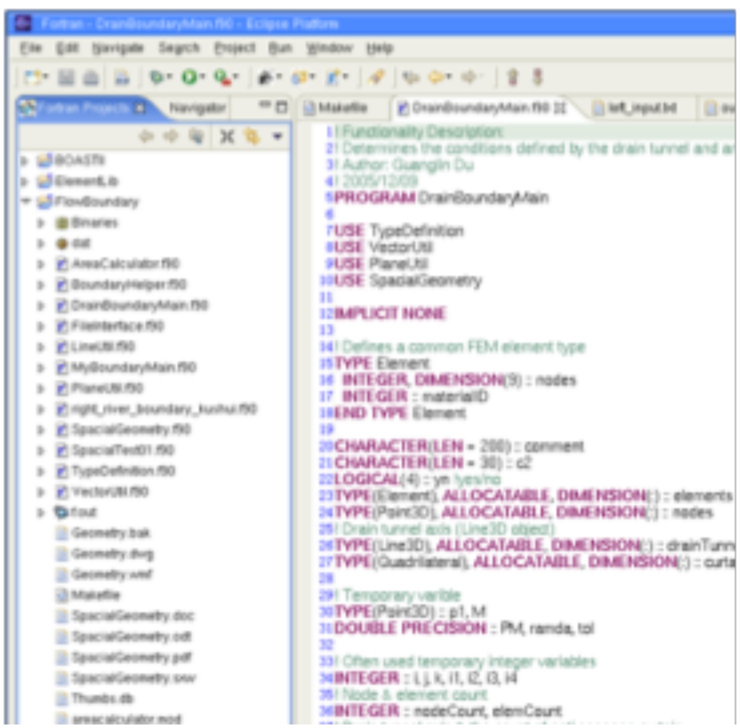
Designing for action

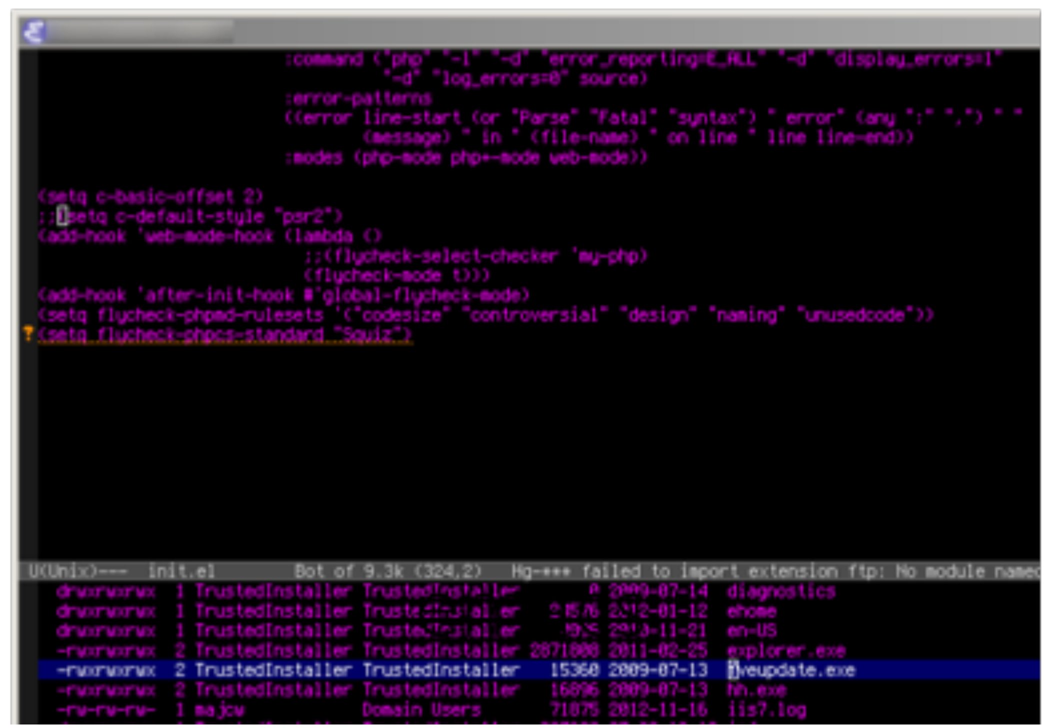
- Key challenge is designing interactions that help users to accomplish their goals

1. Discoverability

- Make it possible to determine possible actions and current state of device

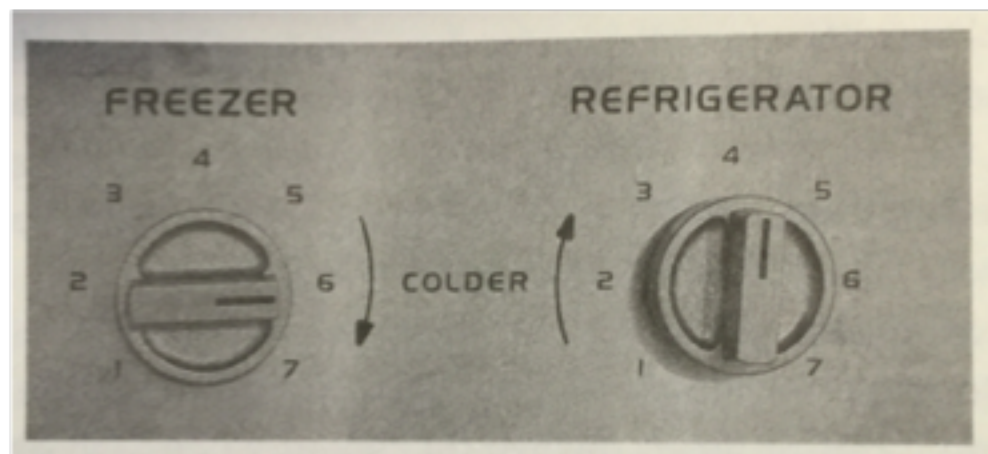
- Which has more discoverable commands: Eclipse or emacs?





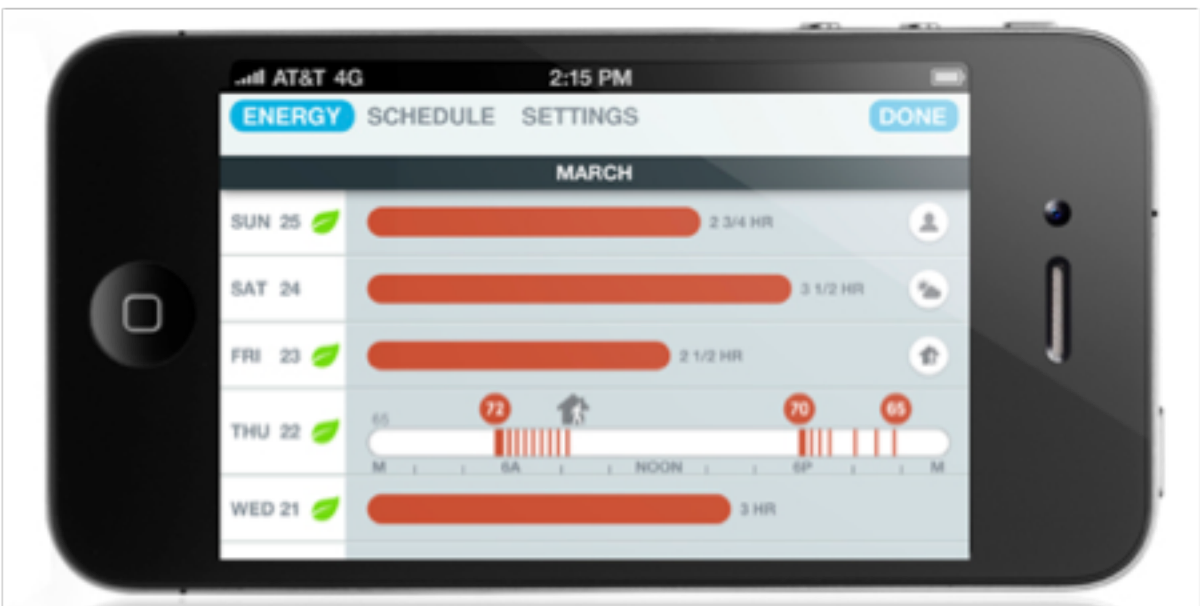
2. Feedback

- There is full and continuous info about the results of actions and the current state



3. Conceptual model

- Design projects all of the information needed to create conceptual model.



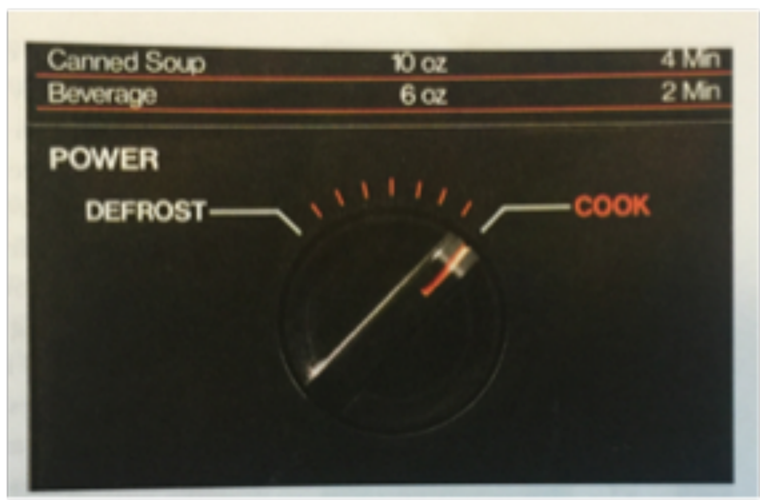
4. Affordances

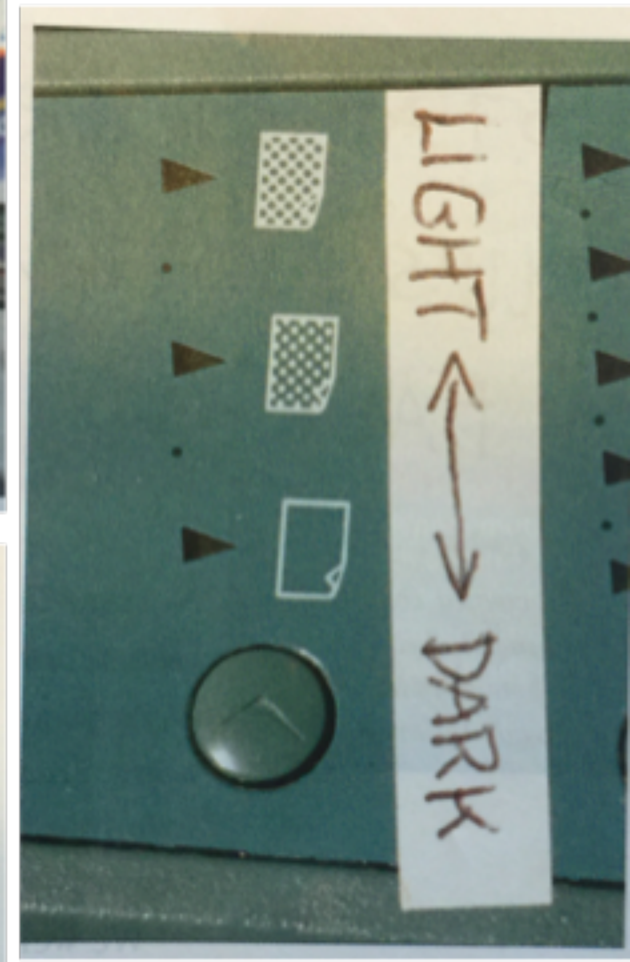
- The proper affordances exist to make the desired actions possible.
- Affordance: an action that can be taken with an artifact to change its state

Browser	Tabbed browsing	Pop-up blocking [note 1]	Incremental search	Ad filtering	Page zooming [note 2]	Full text search of history	Content-modal dialogs [note 3]
Amaya	Yes	N/A	No	No	Yes	No	?
AOL Explorer	Yes	Yes	No	No	Yes	No	?
Arora	Yes	Yes	Yes	Yes	Yes	No	No
Avant	Yes	Yes	No	Yes	Yes	No	?
Camino	Yes	Yes	Yes	Yes	Yes	No	?
Chromium	Yes	?	Yes	?	Yes	?	?
Dillo	Yes	N/A	No	No	No	No	No
Dooble	Yes	Yes	Yes	Yes	Yes	Yes	?
ELinks	Yes	N/A	Yes	N/A	N/A	No	No [note 4]
Flock	Yes	Yes	Yes	Yes	No	No	?
Galeon	Yes	Yes	Yes	Yes	Yes	No	No
Google Chrome	Yes	Partial [note 5]	Yes	No [note 6]	Yes	Yes	No [note 7]

5. Signifiers

- Effective use of signifiers to communicate discoverability and feedback

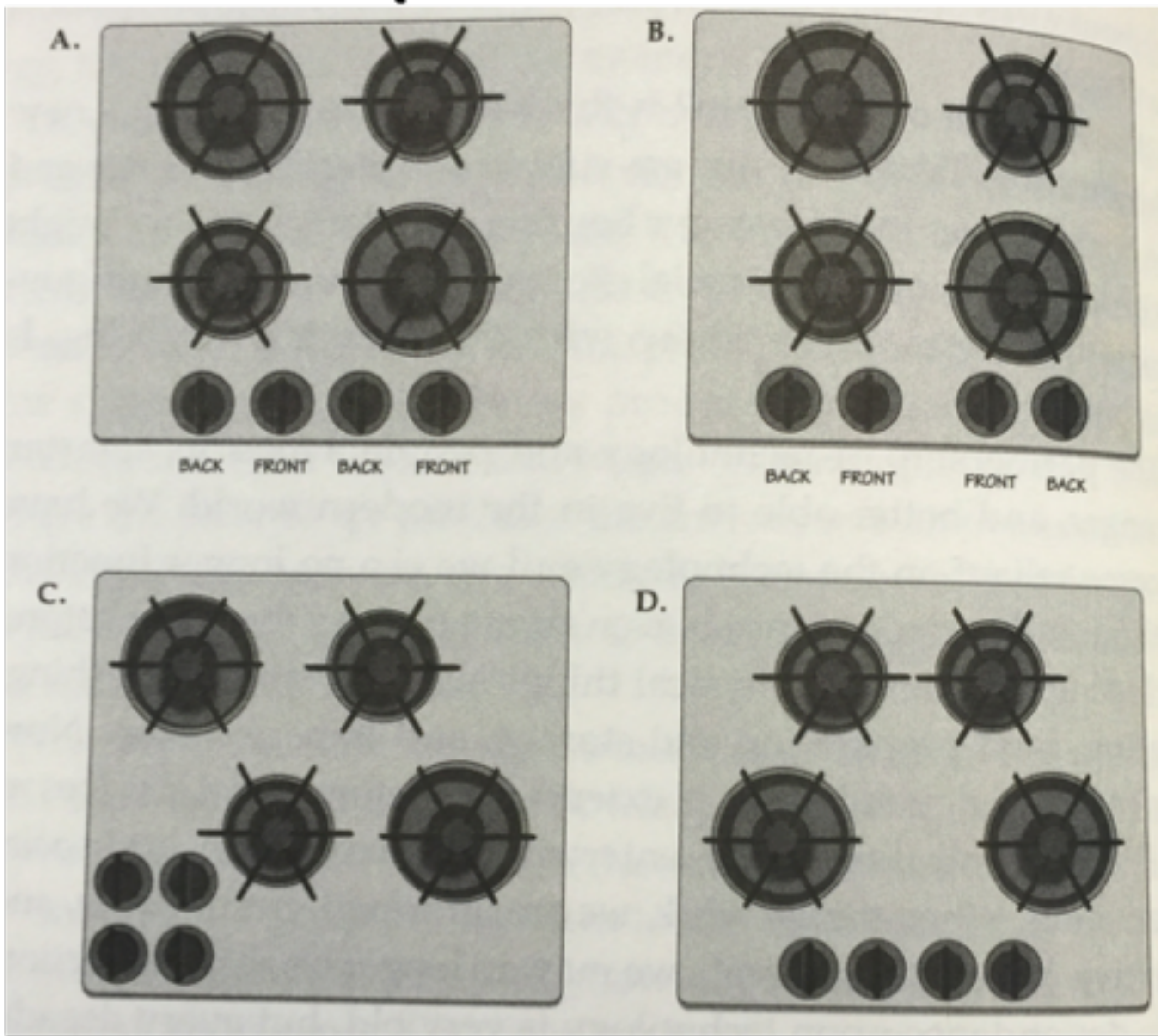




6. Mapping

- The relationship between controls and their actions follows the principles of good mapping

Example - burners

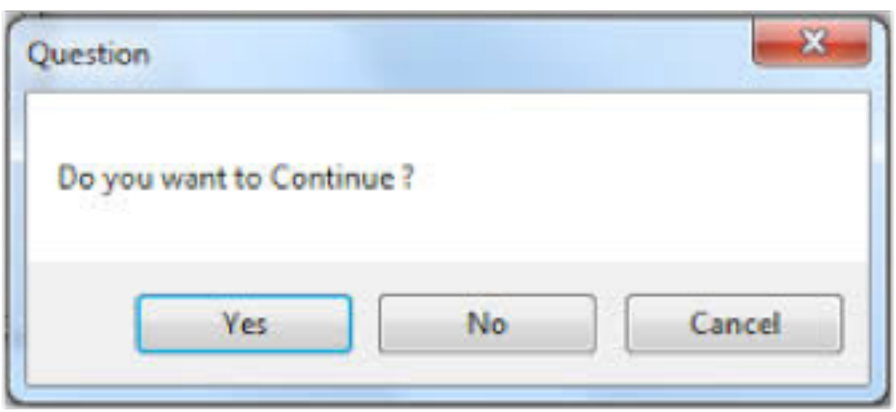


Natural mapping

- Best mapping: controls mounted next to item to be controlled
- Second best mapping - controls as close as possible to item to be controlled
- Third best mapping - controls arranged in same spatial configuration

Consistent mapping

- Control consistently leads to same action
- Facilitates System 1 - taking action always leads to the same effect



7. Constraints

- Provide physical, logical, semantic, cultural constraints to guide actions and ease interpretation

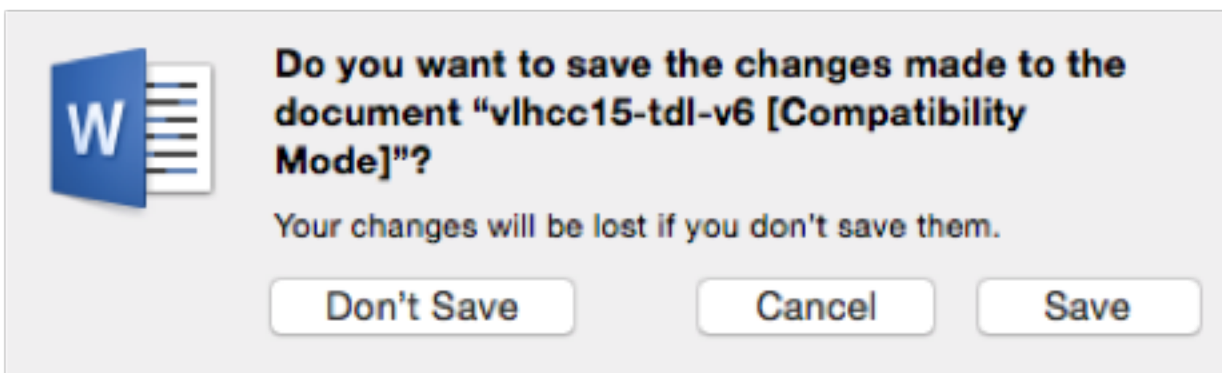
Physical constraints

- Constrain possible operators (e.g., round peg, square whole)

- Rely on properties of artifact, no training required

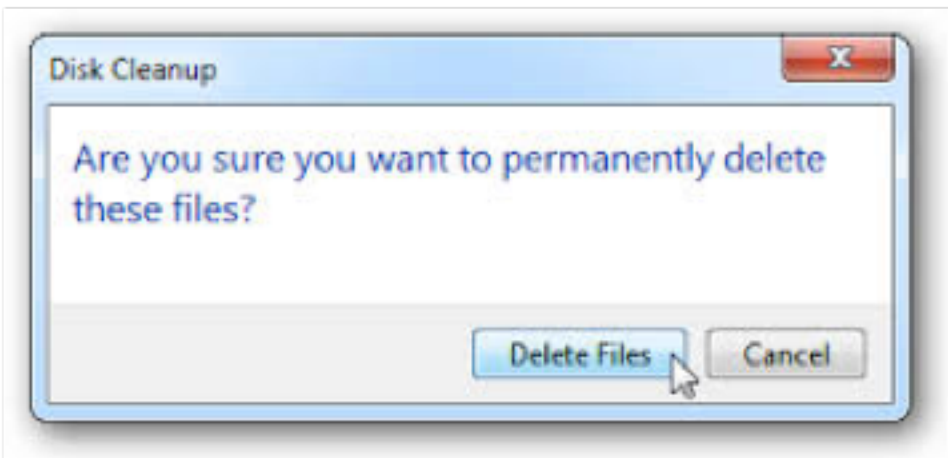
Lock ins

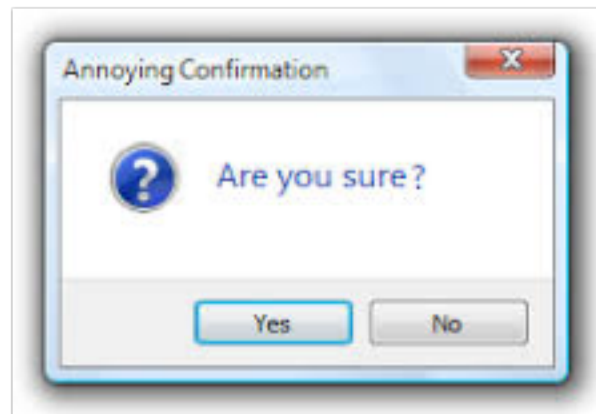
- Keeps an operation active, preventing someone from prematurely stopping



Lock outs

- Prevents an event from occurring



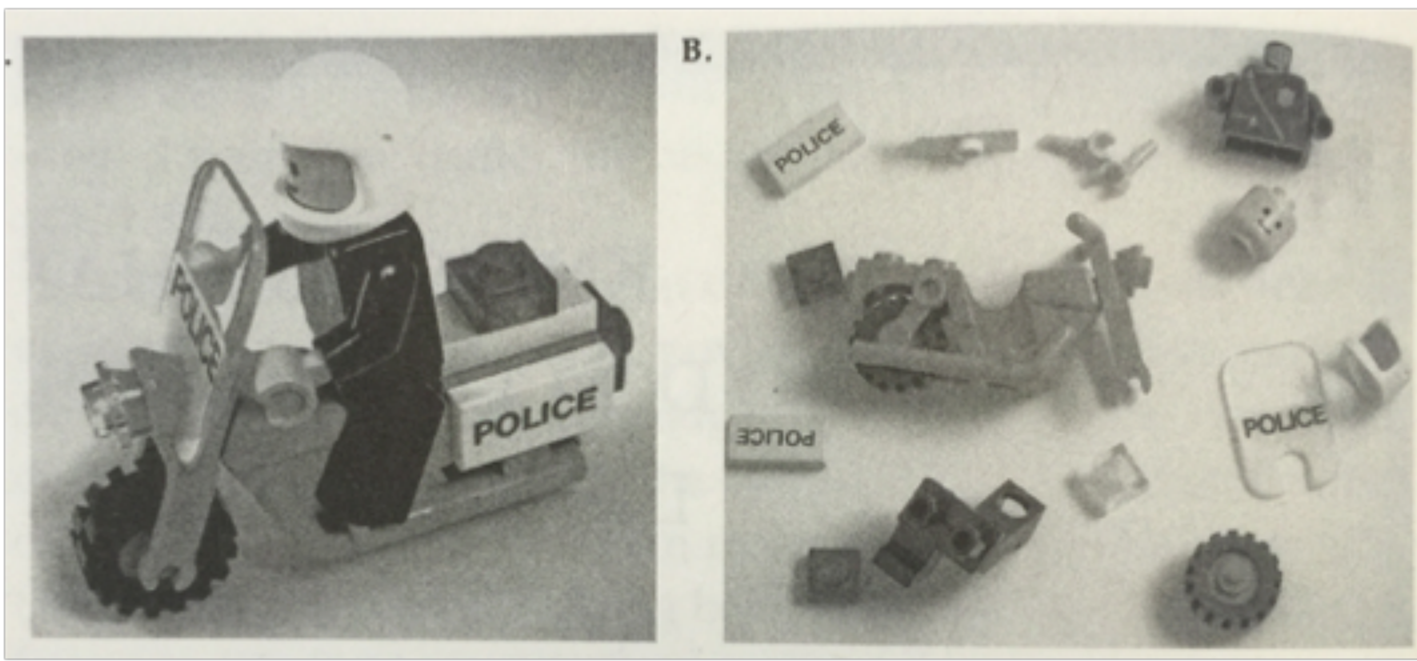


Interlocks

- Force actions to take place in the proper sequence

Cultural, semantic, logical constraints

- Norms, conventions that describe possible actions



Example: faucets

- Control 2 variables: temperature, rate of flow
- Physical model: water enters through 2 pipes
- Solutions:
  - Separate controls for hot and cold
  - Control only temp / control only ant
  - On / off
  - One control

Example: faucets

- Mapping problems:
  - Which know controls hot and which cold?
  - How do you change temperature w/ out flow rate?
  - How do you change flow w/out temperature?
  - Which direction increases water flow?

Example: faucets

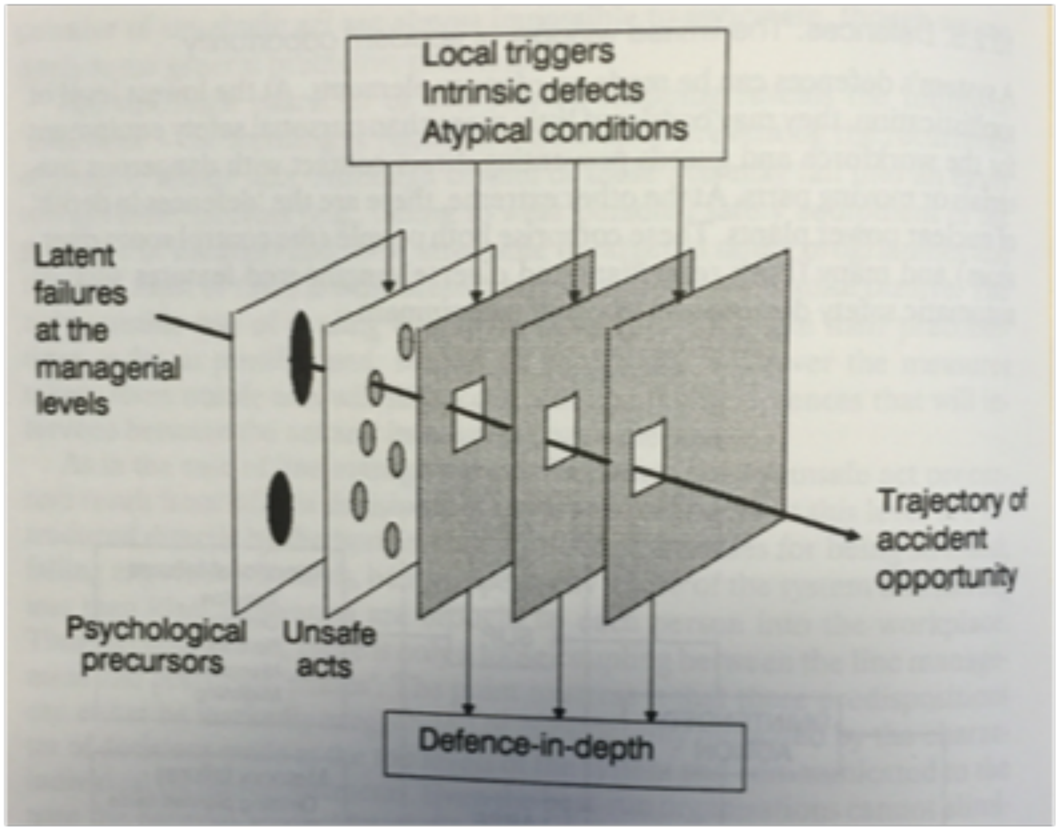
- Standard conventions: left hot, right cold; counter-clockwise turns it on
- But
  - Not in England
  - Not always on shower controls
  - Not always for blade controls

Human Error

What causes disasters?

- Mechanical malfunction?
- Poor design?
- Human error?

Swiss cheese model



- Accidents must penetrate levels of system defenses

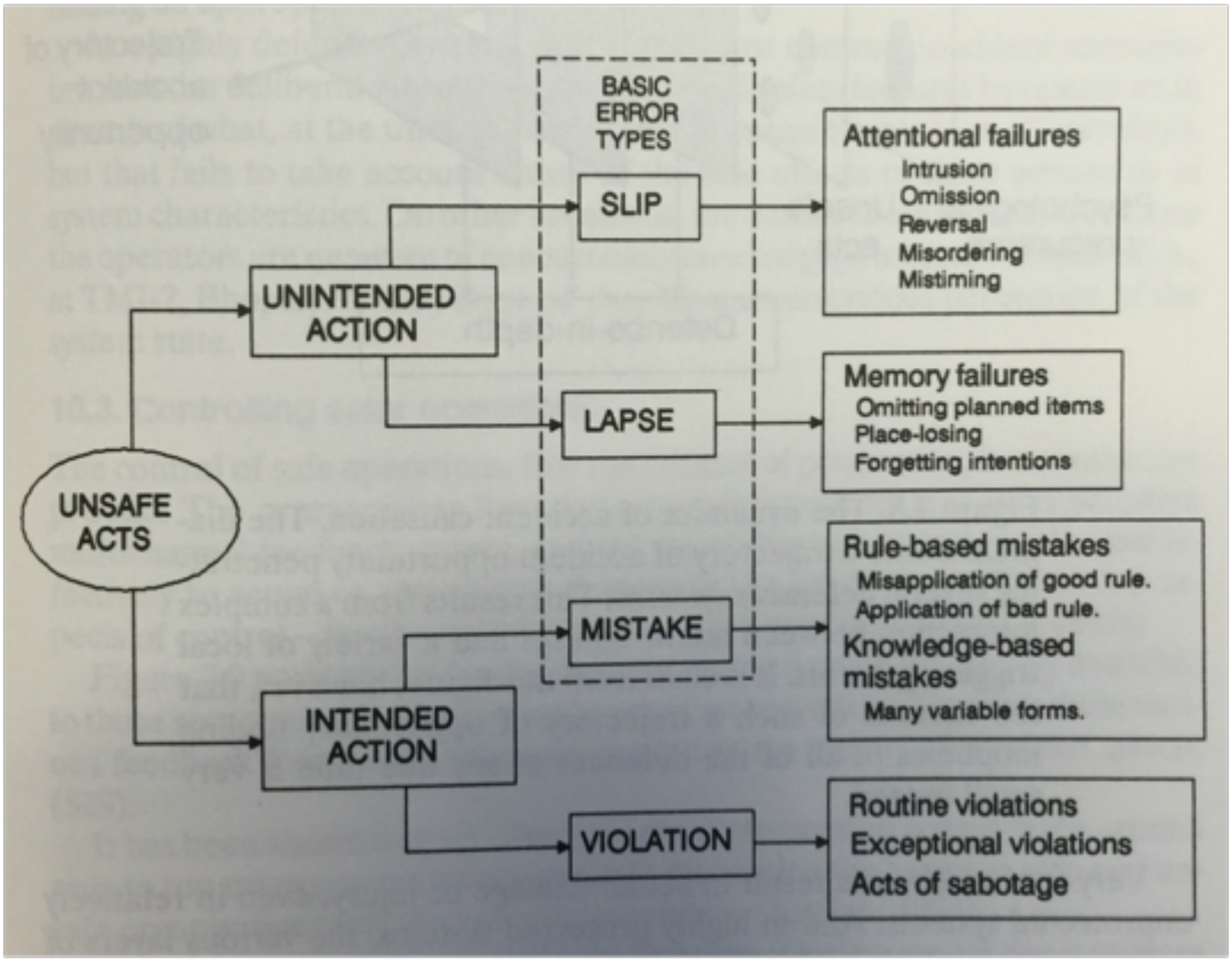
Root cause analysis

- Keep asking question to determine causes for actions
- Human error only part of the chain
- Example
    - 2010 F-22 crash that killed pilot
    - Official cause: pilot error - pilot failed to take corrective action
    - IG report: pilot was probably unconscious

Case Study No. 1: Three Mile Island

Chain of events and active errors	Contributing conditions and latent failures
Maintenance crew introduces water into the instrument air system.	Although this error had occurred on two previous occasions, the operating company had not taken steps to prevent its recurrence. *(Management failure)*
Turbine tripped. Feedwater pumps shut down. Emergency feedwater pumps come on automatically, but flow blocked by two closed valves.	The two block valves had been erroneously left in the closed position during maintenance, probably carried out two days prior to the accident sequence. One of the warning lights showing that valves were closed was obscured by a maintenance tag. *(Maintenance failures)*
Rapid rise in core temperature and pressure, causing the reactor to trip. Relief valve (PORV) opens automatically, but then sticks in the open position. The scene is now set for a loss of coolant accident (LOCA) 13 seconds into the emergency.	During an incident at the Davis – Besse plant (another Babcock & Wilcox PWR) in September 1977, the PORV also stuck open. The incident was investigated by Babcock & Wilcox and the U.S. Nuclear Regulatory Commission. However, these analyses were not collated, and the information obtained regarding appropriate operator action was not communicated to the industry at large. *(Regulatory failure)*
Operators fail to recognise that the relief valve is stuck open. Primary cooling system now has hole in it through which radio – active water, under high pressure, pours into the containment area, and thence down into basement.	1. Operators were misled by control panel indications. Following an incident 1 year earlier, an indicator light had been installed. But this merely showed whether or not the valve had been commanded shut: it did not directly reveal valve status. *(Design and management failures)* 2. Operators wrongly assumed that high temperature at the PORV drain pipe was due to a chronically leaking valve. The pipe temp – erature normally registered high. *(Management/ procedural failure)*
Operators failed to diagnose stuck – open PORV for more than 2 hours. The resulting water loss caused significant damage to the reactor.	1. The control panel was poorly designed with hundreds of alarms that were not organised in a logical fashion. Many key indications were sited on the back wall of the control room. More than 100 alarms were activated with no means of suppressing unimportant ones. Several instruments went off – scale, and the computer printer ran more than 2 hours behind events. *(Design and management failures)* 2. Operator training, consisting largely of lectures and work in the reactor simulator, provided an inadequate basis for coping with real emergencies. Little feedback given to students, and training programme was insufficiently evaluated. *(Training and management failures)*
The crew cut back the high – pressure injection (HPI) of the water into the reactor coolant system, thus reducing the net flow rate from around 1000 gallons/min to about 25 gallons/min. This 'throttling' caused serious core damage.	1. Training emphasised the dangers of flooding the core. But this took no account of the possibility of a concurrent LOCA. *(Training and management failures)* 2. Following the 1977 Davis – Besse incident, the Nuclear Regulatory Commission issued a publication that made no mention of the fact that these operators had interrupted the HPI. The incident appeared under the heading of "valve malfunction" not "operator error". *(Regulatory failure)*

Psychological types of unsafe acts



Violation

- Error occurred because user **intended** the erroneous output
- Routine violation - user always intends to do it
  - Noncompliance is so frequent it is ignored
  - E.g., running a red light
- Exceptional - only in some cases
- Sabotage - intended destruction

Mistakes

- User **formulated** the wrong goal or plan
  - Executing action will not achieve goal
- Rule based: appropriately diagnosed situation, but chosen erroneous course of action
- Knowledge based: does not have correct information

Slips

- Attentional failure - user **intended** to do correct action, but did not actually execute action
- Example: forgot to turn off the gas burner on the stove after cooking

Strong habit intrusion

- Performance of some well-practiced activity in familiar surroundings

- Intention to depart from custom

- Failure to make an appropriate check

- Example: start trip to frequent destination, forget going somewhere else

Omissions

- May be interrupted, forgetting intention to act
- "I picked up my coat to go out when the phone rang. I answered it and then went out of the front door without my coat."

Perceptual confusions

- Take frequent action very often, don't perform perceptual check to verify it is the correct one
- Example: "I began to pour coffee into the sugar bowl"

Mistimed checks

- Highly automated System 1 activity that is interrupted
- Error in resuming activity because usually unconscious.
- Example - interrupted in the middle of tying shoes

Group activity

Group activity

- In groups of 3 or 4
- Pick a (complex) application or website
- List violations of Norman's principles for designing for action
  - List name of principle (e.g., discoverability)
  - Identify a user goal and relevant features of the application
  - Explain how the design violates the principle

Norman's designing for action principles

1. Discoverability - make it possible to determine possible actions and state
2. Feedback - full and continuous feedback about result of action
3. Conceptual Model - design communicates info for conceptual model
4. Affordances - desired affordances exist
5. Signifiers - effective use of signifiers to communicate
6. Mapping - relationship between controls and goals uses good mapping
7. Constraints - physical, logical, semantic, cultural constraints