Human Error

Human Factors

Examining errors

"Analysis of errors or performance breakdowns reveals which aspects of the task are the largest contributors to poor performance, and thus where performance-aiding efforts should be concentrated. Analysis of expert performance defines candidate strategies that may be useful to transfer to less experienced practitioners, for example through training or on-line advice" *[Roth, Patterson, Mumaw, in Encyclopedia of Software Engineering]*

Slips, lapses, and mistakes.

- A slip is a failure in the execution of an action as planned.
- A lapse is in omission to execute an action as planned due to a failure of memory.
- A mistake is an error in planning an action irrespective of whether an action is carried out correctly.

Example of a slip (CHIRP incident database)

BAC 1-11: My first officer was flying the leg. After T/O I carried out the usual checks. Brakes, U/C up, PAX notices off etc. Weather; lovely blue sky. W/V 270/18, Temp +30C! At 1500 feet I noticed the flaps were retracted, I thought John had retracted them early. Usually the flap is retracted at 2000 feet plus in VFR or 3000 noise abatement. Almost immediately he mentioned that the flaps were retracted. 'Oh, I see you have brought the flaps in" he said. "No" I replied "I haven't touched them". He said he hadn't either. Shortly after this he noticed the U/C was still extended. I raised it at 220 knots. There can be no doubt I raised the flaps instead of the U/C after take-off. I had no memory at all of doing this. Why would I do this potentially dangerous thing on an aircraft with which I was completely familiar? I have no idea: no sickness, no stress, nothing dramatic personally.

Slips: capture, data driven, description

- A capture error is a frequently used action which overrides the intended action (eg. same initial sequence) eg. withdrawing cash when meant to check balance.
  - "turning off the antibiotics IV" overridden by "turning off the infusion pump completely,"
- A data-driven error – when unconscious processing of external data interferes with what you had intended to do.
  - "I was assigning a visitor a room to use. I decided to call the department secretary to tell him the room number. I used the telephone in the alcove outside the room, with the room number in sight. Instead of dialing the secretary's number, which I know very well – I dialed the room number"
- Description: right action, wrong object (similar buttons).

Slips: Associative activation error

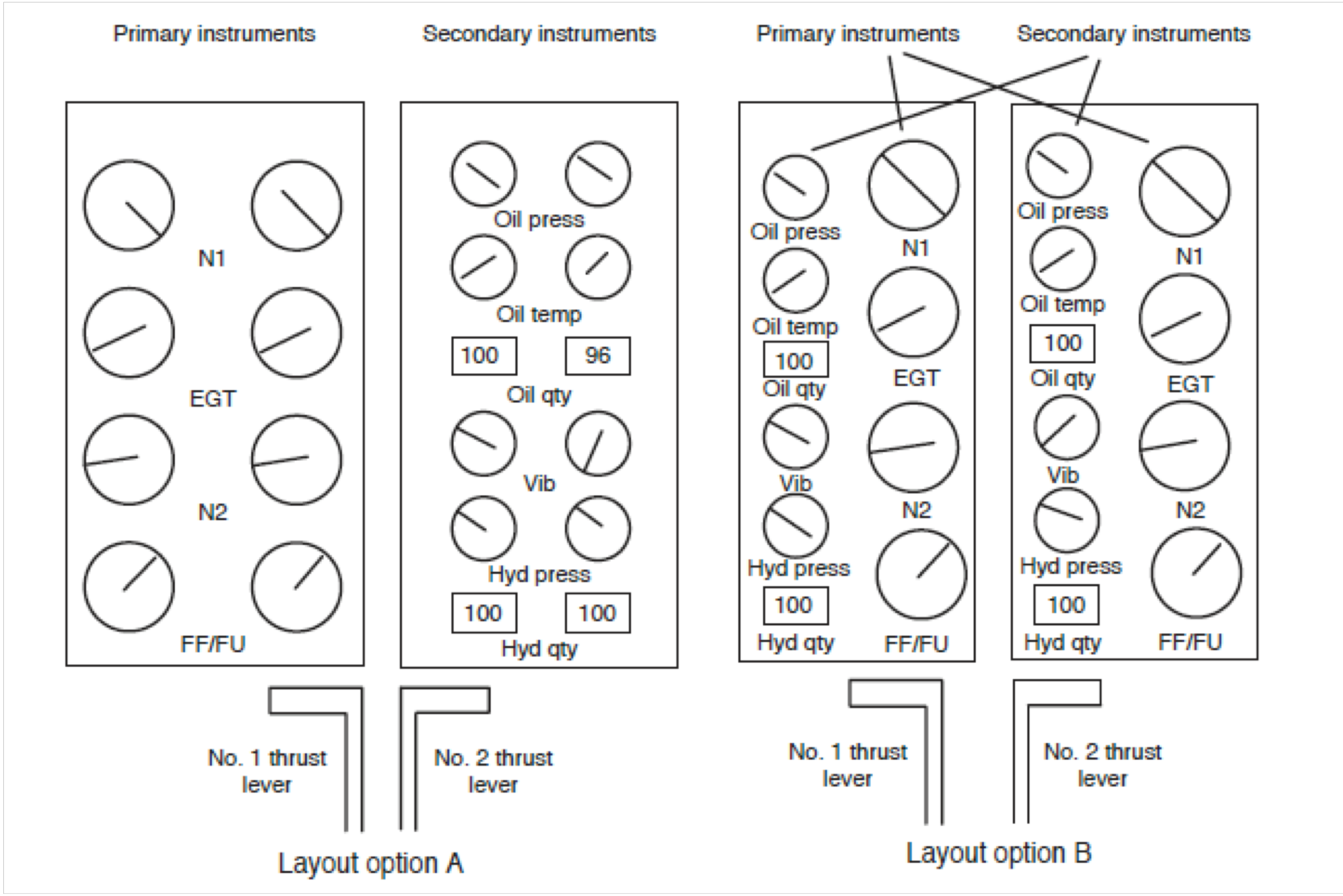
- An associative-activation error – when internal thoughts interfere with what you are supposed to be doing.
  - “My office phone rang. I picked up the receiver and bellowed “come on in” at it”.
  - A nurse intends to decrease a value using the decrement function, but pushes the down arrow key (which moves to the next field) instead of the minus key. (Action specification slip).

Lapses

- Failure in memory (interruption, loss of activation; place losing, loss of intention).
- After an interruption, procedure may be recommenced further along the sequence, having omitted one or more tasks.
  - A doctor was called out of the room to answer an urgent call and afterwards he went to the room of a different patient who was next in the queue. (Loss of activation)
  - Related to goal level in Norman’s model.
- Intention to begin a task is delayed, (e.g. waiting for some system state to be achieved). Attention becomes focussed elsewhere and start signal is missed.

Example of a mistake

- Approximately 13 minutes into the flight the turbofan on the No.1 (left) engine fractured causing a series of compressor stalls in that engine. The pilots did not know what had happened; the indications they received were excessive vibration felt throughout the airframe, noise and a smell of fire in the cockpit.Their initial reaction was that they had a fire. The following comments were spoken by the first officer: “It's a fire Kevin. It's a fire coming through.” In response the commander disengaged the auto throttle and said “Which one is it though?” The 1st officer replied “Its the le... its the right one.” The commander then requested the first officer to throttle it back. In fact it was the left hand engine that was faulty; the first officer had identified the wrong engine and it was a perfectly healthy right engine that was throttled back.
- AAIB Kegworth accident report



Whittingham “The blame machine – why human error causes accidents”

Knowledge-based mistakes

Availability bias

- recently presented information and information that is currently visible are given undue weight in decision making.

Anchoring

- people revise their hypothesis based on their initial model

Confirmation bias

- people richly interpret ambiguous scenes to reach an explanatory model. They then seek confirmation and disregard disconfirming information.

Selectivity

- problem solvers attention is directed to psychologically salient aspects of a problem in preference to logically important aspects.

Overconfidence and frequency gambling also factors.

Framing – “90% fat free!” vs. “10% fat”

Kegworth accident

- Availability
  - There was no fire bell but this did not stop them diagnosing a fire
  - Fire drills are a common simulator training exercise
- Confirmation
  - When the Kegworth pilots idled the wrong engine the symptoms went away, confirming the (incorrect) diagnosis (symptoms improved as less fuel was getting to left engine after disengaging autothrottle).
- Selectivity
  - Smoke in the cockpit during the Kegworth accident perceptually salient.

Modes

- Why have modes – finite input and display space.
- Modes increase memory and knowledge demands.
- Mode error when an intention is executed in a way appropriate for one mode, when in fact the system is in a different mode (error of commission).
- Losing track of which mode the system is in is a critical component of a mode error.
- Strasbourg accident due to mode error.

Strasbourg accident

January 20, 1992, Airbus A320 Lyon -> Strasbourg

The pilots had expected a circling approach, in which the airplane was to fly over the airport and then turn back and land in a direction different from that of the approach. However, after planning and preparing for the circling approach, air traffic control informed the pilots that only a straight in approach was immediately available. The pilots accepted a clearance for a straight in approach, but had to begin preparations for the new approach, in a shorter period of time than had been available for the initial approach.

Strasbourg accident – why?

- Selected mode for automatic pilot
- Major cause: selection of the descent rate of **3300** ft/min instead of descent rate of **800** ft/min (enabling an approach plan of **3.3** deg)…
  - transcripts indicate that the crew was more worried about *heading* than *altitude & speed*

Modes


SPD
TRK LAT
ALT
LVL/CH
FPA
100

TRK
FPA
00100
-3.30
HDG TRK
V/S FPA
100
1000
SPD MACH
METRIC ALT
UP
PUSH TO LEVEL OFF
DN
AP 1
AP2
LOC
A/THR
EXPED
APPR


SPD
HDG
LAT
ALT
LVL/CH
V/S
100

HDG
V/S
00100
-3300
HDG TRK
V/S FPA
100
1000
SPD MACH
METRIC ALT
UP
PUSH TO LEVEL OFF
DN
AP 1
AP2
LOC
A/THR
EXPED
APPR

Modes


SPD
TRK
LAT
ALT
FPA
100
- - -
TRK
FPA
00100
-3.30
HDG
TRK
V/S
FPA
100
1000
METRIC
ALT
UP
PUSH
TO
LEVEL
OFF
DN
SPD
MACH
AP 1
AP2
LOC
A/THR
EXPED
APPR


SPD
HDG
LAT
ALT
V/S
100
- - -
HDG
V/S
00100
-3300
HDG
TRK
V/S
FPA
100
1000
METRIC
ALT
UP
PUSH
TO
LEVEL
OFF
DN
SPD
MACH
AP 1
AP2
LOC
A/THR
EXPED
APPR

Modes

- Increase demands on situation assessment and awareness.
- Difficulty is conditional on how the interface signals device mode (observability) and on characteristics of the distributed set of agents who manage incidents.
- Difficulty of keeping track of mode varies according to task context (time-pressure, interleaved multiple tasks, workload).
- Eliminate unnecessary modes, increase tolerance to mode error, provide better indications of mode status and better feedback about mode changes.

Hiding interesting changes, events and behaviours (evaluation errors)

- Basic unit of display often still digital value.
- Failure to develop representations that reveal change and highlight events in monitored process had contributed to incidents.
- In Apollo 13, an explosion occurred in the oxygen portion of the cryogenics system (audio).
- The mission controller (EECOM) monitoring this system was examining a screen filled with digital values.
- It took 54 minutes before the correct hypothesis was formulated regarding the pattern of disturbances.
- Two values, out of 56 changing numbers had changed anomalously.

Transcript

55:52:58 - *CapCom:* "13, we've got one more item for you, when you get a chance. We'd like you to stir up your cryo tanks. In addition, I have shaft and trunnion..."

55:53:06 - *Swigert:* "Okay." *(over CapCom)*

55:53:07 - *CapCom:* "...for looking at comet (J. C.) Bennett (19691), if you need it."

55:53:12 - *Swigert:* "Okay. Stand by."

55:55:20 - Swigert: "Okay, Houston, we've had a problem here."

55:55:28 - CapCom: "This is Houston. Say again please."

55:55:35 - Lovell: "Ah, Houston, we've had a problem. (pause) We've had a main B bus undervolt."

Local loop

Guido: *"Flight, Guidance."*

Flight: *"Go, Guidance."*

Guido: *"We've had a (Command Module Computer - CMC) hardware restart. I don't know what it was."*

Flight: *"GNC you want to look at it?"*

GNC: *"(garbled)"*

Flight: *"Roger. See a hardware restart?"*

Local loop

Flight: *"You see a AC bus undervolt there Guidance, (correcting himself) er, EECom?"*

EECom: *"Negative, Flight."*

Flight: "I believe the crew reported it."

CapCom: *"We got a main B undervolt."*

EECom: *"Okay, Flight we've got some instrumentation flags. Let me add them up."*

Flight: *"Rog."*

EECom: *"We've may have had an instrumentation problem, Flight."*

Flight: *"Rog."*

Local loop

Inco: *"Flight, Inco."*

Flight: *"Go, Inco."*

Inco: *"We switched to widebeam width about the time he had that problem."*

Flight: *"Okay, you say you went to widebeam there?"*

Inco: *"Yes."*

Flight: *"See if you can correlate the times, get the time you went to wide beam, Inco."*

[Gene Kranz stated in the Apollo 13 Mission Operations Report that "At this time, I felt we had had a major short circuit that knocked much of the instrumentation offline, and that it might be related to the HGA (High-Gain Antenna) anomaly that occurred earlier."]

Time 55:53:47

LM12839 CSM ECS-CRYO TAB 0613

CTE 055:46:51 ( ) GET 055:53:47 ( ) SITE

-------LIFE SUPPORT--------

GF3571	LM CABIN P	PSIA	
CF0001	CABIN P	PSIA	5.1
CF0012	SUIT P	PSIA	4.3
CF0003	SUIT ΔP	IN H20	-1.68
CF0015	COMP ΔP	P PSID	0.30
CF0006	SURGE P	P PSIA	891
	SURGE QTY	LB	3.67
	02 TK 1 CAP	ΔP PSID	21
	02 TK 1 CAP	ΔP PSID	17
CF0036	02 MAN P	PSIA	105
CF0035	02 FLOW	LB/HR	0.181
CF0008	SUIT T	F	50.5
CF0002	CABIN	F	65
CF0005	CO2 PP	MMHG	1.5

------------H20------------

CF0009	WASTE	PCT	24.4
	WASTE	LB	13.7
CF0010	POTABLE	PCT	104.5
	POTABLE	LB	37.6
CF0460	URINE NOZ T	F	70
CF0461	H2O NOZ T	F	72

-----PRIMARY COOLANT-----

CF0019	ACCUM QTY	PCT	34.4
CF0016	PUMP P	PSID	45.0
SF0260	RAD IN T	F	73.8
CF0020	RAD OUT T	F	35
CF0181	EVAP IN T	F	45.7
CF0017	STEAM T	F	64.9
CF0034	STEAM P	PSIA	.161
CF0018	EVAP OUT T	F	44.2
SF0266	RAD VLV 1/2		ONE
CF0157	GLY FLO	LB/HR	215

----SECONDARY COOLANT----

CF0072	ACCUM QTY	PCT	36.8
CF0070	PUMP P	PSID	9.3
SF0262	RAD IN T	F	76.5
SF0263	RAD OUT T	F	44.6
CF0073	STEAM P	PSIA	.2460
CF0071	EVAP OUT T	F	66.1
CF0120	H20-RES	PSIA	25.8
	TOTAL FC CUR	AMPS	

--------CRYO SUPPLY--------		02-1	02-2	H2-1	H2-2
SC0037-38-39-40 P	PSIA	876.5	906	225.7(03-1)	235.1
SC0032-33-30-31 QTY	PCT	77.63	O/S	73.24	74.03
SC0041-42-43-44-T	F	-189	-192	-417	-416
QTY	LBS	251.1	260.0	20.61	20.83

Apollo 13, 906
1/22/92

Time 55:54:47

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LM12839                          CSM ECS-CRYO TAB                                      0613

CTE 055:54:45     (           )     GET 055:54:47        (          )        SITE
-------LIFE SUPPORT--------                     -----PRIMARY COOLANT-----
GF3571  LM CABIN P          PSIA|               CF0019  ACCUM QTY PCT          34.4
CF0001  CABIN   P           PSIA|   5.1         CF0016  PUMP P     PSID        45.0
CF0012  SUIT    P           PSIA|   4.1         SF0260  RAD IN T       F       73.8
CF0003  SUIT    Δ P       IN H20   -1.68
CF0015  COMP    Δ P       P PSID|   0.32
CF0006  SURGE     P       P PSIA|  892          CF0020  RAD OUT T      F       35
        SURGE QTY             LB|   3.68        CF0181  EVAP IN T      F       45.7
   02   TK  1  CAP    Δ P PSID|    20           CF0017  STEAM T        F   |   64.9
   02   TK  1  CAP    Δ P PSID|    15           CF0034  STEAM P    PSIA    |     .161
                                                CF0018  EVAP OUT T     F       44.2
CF0036  02 MAN P            PSIA   105
CF0035  02 FLOW            LB/HR     0.163
                                                SF0266  RAD VLV 1/2             ONE
CF0008  SUIT T                 F|   50.2        CF0157  GLY FLO LB/HR         215
CF0002  CABIN                  F|   66          ----SECONDARY COOLANT----
CF0005  CO2 PP              MMHG     1.5        CF0072  ACCUM QTY PCT      |   36.8
------------H20------------                     CF0070  PUMP P    PSID     |    9.3
CF0009  WASTE                PCT|   24.2        SF0262  RAD IN T      F    |   76.5
        WASTE                 LB|   14.2        SF0263  RAD OUT T     F    |   44.6
CF0010  POTABLE              PCT|  104.5        CF0073  STEAM P   PSIA           .2460
        POTABLE               LB|   37.6        CF0071  EVAP OUT T    F        66.1
CF0460  URINE NOZ T            F|   71          CF0120  H20-RES   PSIA         25.8
CF0461  H2O NOZ T              F|   72.1        TOTAL FC CUR      AMPS
--------CRYO SUPPLY------------------02-1------02-2-------H2-1-----------H2-2---
SC0037-38-39-40 P           PSIA      874.9     1008.3      225.7(03-1)     235.1
SC0032-33-30-31 QTY          PCT       75.45      60          73.24          74.03
SC0041-42-43-44-T              F     -190       -160        -417            -416
              QTY            LBS      251.1      O/S          20.61          20.83
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Apollo 13, 1008.3
1/22/92

Time 55:54:53

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LM12839                      CSM ECS-CRYO TAB                                  0613

CTE 055:57:02    (         )    GET 055:54:53    (         )               SITE
-------LIFE SUPPORT--------                      -----PRIMARY COOLANT-----
GF3571  LM CABIN P       PSIA                    CF0019  ACCUM QTY PCT         34.4
CF0001  CABIN  P         PSIA    5.6             CF0016  PUMP P    PSID        45.3
CF0012  SUIT   P         PSIA    4.13            SF0260  RAD IN T      F       73.8
CF0003  SUIT     P     IN H20   -1.8
CF0015  COMP     P     P PSID    0.27
CF0006  SURGE    P     P PSIA  889               CF0020  RAD OUT T     F       35.2
        SURGE QTY          LB    3.9             CF0181  EVAP IN T     F       45.7
   02  TK  1  CAP      P PSID   19               CF0017  STEAM T       F       64.7
   02  TK  1  CAP      P PSID   17               CF0034  STEAM P   PSIA          .161
                                                 CF0018  EVAP OUT T    F       44.6
CF0036  02 MAN P         PSIA  108
CF0035  02 FLOW         LB/HR    0.178
                                                 SF0266  RAD VLV 1/2            ONE
CF0008  SUIT T              F   50.5             CF0157  GLY FLO LB/HR        215
CF0002  CABIN               F   65               ----SECONDARY COOLANT----
CF0005  CO2 PP           MMHG    1.6             CF0072  ACCUM QTY PCT         36.8
------------H20------------                      CF0070  PUMP P    PSID         9.3
CF0009  WASTE             PCT   28.9             SF0262  RAD IN T    F         76.5
        WASTE              LB   14.9             SF0263  RAD OUT T   F         45.1
CF0010  POTABLE           PCT  109.9             CF0073  STEAM P   PSIA          .2460
        POTABLE            LB   39.1             CF0071  EVAP OUT T  F         65.9
CF0460  URINE NOZ T         F  105               CF0120  H20-RES   PSIA        26.2
CF0461  H2O NOZ T           F   78               TOTAL FC CUR      AMPS
--------CRYO SUPPLY-----------------02-1------02-2-------H2-1-----------H2-2---
SC0037-38-39-40 P         PSIA      872        19      225.7(03-1)     235.1
SC0032-33-30-31 QTY       PCT        72.3      01.17    73.24           74.03
SC0041-42-43-44-T         F        -189        O/S     -417            -416
                QTY       LBS       251.1      O/S      20.61           20.83
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Hiding interesting changes

- What is the point of the computer as a medium for the display of data if it does not reduce practitioner memory loads?
- None of the operators noticed the number for oxygen tank 2 during four crucial seconds.
- Could we do any better today?

Time 55:53:47

LM12839 — CSM ECS-CRYO TAB — 0613

CTE 055:46:51 ( ) GET 055:53:47 ( ) SITE

-------LIFE SUPPORT--------

GF3571	LM CABIN P	PSIA	
CF0001	CABIN P	PSIA	5.1
CF0012	SUIT P	PSIA	4.3
CF0003	SUIT ΔP	IN H20	-1.68
CF0015	COMP ΔP	P PSID	0.30
CF0006	SURGE P	P PSIA	891
	SURGE QTY	LB	3.67
02	TK 1 CAP	ΔP PSID	21
02	TK 1 CAP	ΔP PSID	17
CF0036	02 MAN P	PSIA	105
CF0035	02 FLOW	LB/HR	0.181
CF0008	SUIT T	F	50.5
CF0002	CABIN	F	65
CF0005	CO2 PP	MMHG	1.5

------------H20------------

CF0009	WASTE	PCT	24.4
	WASTE	LB	13.7
CF0010	POTABLE	PCT	104.5
	POTABLE	LB	37.6
CF0460	URINE NOZ T	F	70
CF0461	H2O NOZ T	F	72

-----PRIMARY COOLANT-----

CF0019	ACCUM QTY	PCT	34.4
CF0016	PUMP P	PSID	45.0
SF0260	RAD IN T	F	73.8
CF0020	RAD OUT T	F	35
CF0181	EVAP IN T	F	45.7
CF0017	STEAM T	F	64.9
CF0034	STEAM P	PSIA	.161
CF0018	EVAP OUT T	F	44.2
SF0266	RAD VLV 1/2		ONE
CF0157	GLY FLO LB/HR		215

----SECONDARY COOLANT----

CF0072	ACCUM QTY	PCT	36.8
CF0070	PUMP P	PSID	9.3
SF0262	RAD IN T	F	76.5
SF0263	RAD OUT T	F	44.6
CF0073	STEAM P	PSIA	.2460
CF0071	EVAP OUT T	F	66.1
CF0120	H20-RES	PSIA	25.8
TOTAL FC CUR		AMPS	

--------CRYO SUPPLY--------

		02-1	02-2	H2-1	H2-2
SC0037-38-39-40 P	PSIA	876.5	906	225.7(03-1)	235.1
SC0032-33-30-31 QTY	PCT	77.63	O/S	73.24	74.03
SC0041-42-43-44-T	F	-189	-192	-417	-416
QTY	LBS	251.1	260.0	20.61	20.83

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-------LIFE SUPPORT--------

GF3571	LM CABIN P		PSIA	
CF0001	CABIN P		PSIA	5.1
CF0012	SUIT P		PSIA	4.1
CF0003	SUIT Δ P		IN H20	-1.68
CF0015	COMP Δ P		P PSID	0.32
CF0006	SURGE P		P PSIA	892
	SURGE QTY		LB	3.68
	02 TK 1 CAP		Δ P PSID	20
	02 TK 1 CAP		Δ P PSID	15
CF0036	02 MAN P		PSIA	105
CF0035	02 FLOW		LB/HR	0.163
CF0008	SUIT T		F	50.2
CF0002	CABIN		F	66
CF0005	CO2 PP		MMHG	1.5

------------H20------------

CF0009	WASTE	PCT	24.2
	WASTE	LB	14.2
CF0010	POTABLE	PCT	104.5
	POTABLE	LB	37.6
CF0460	URINE NOZ T	F	71
CF0461	H2O NOZ T	F	72.1

-----PRIMARY COOLANT-----

CF0019	ACCUM QTY PCT		34.4
CF0016	PUMP P	PSID	45.0
SF0260	RAD IN T	F	73.8
CF0020	RAD OUT T	F	35
CF0181	EVAP IN T	F	45.7
CF0017	STEAM T	F	64.9
CF0034	STEAM P	PSIA	.161
CF0018	EVAP OUT T	F	44.2
SF0266	RAD VLV 1/2		ONE
CF0157	GLY FLO LB/HR		215

----SECONDARY COOLANT----

CF0072	ACCUM QTY PCT		36.8
CF0070	PUMP P	PSID	9.3
SF0262	RAD IN T	F	76.5
SF0263	RAD OUT T	F	44.6
CF0073	STEAM P	PSIA	.2460
CF0071	EVAP OUT T	F	66.1
CF0120	H20-RES	PSIA	25.8
TOTAL FC CUR		AMPS	

--------CRYO SUPPLY------------------

		02-1	02-2	H2-1	H2-2
SC0037-38-39-40 P	PSIA	874.9	1008.3	225.7(03-1)	235.1
SC0032-33-30-31 QTY	PCT	75.45	60	73.24	74.03
SC0041-42-43-44-T	F	-190	-160	-417	-416
QTY	LBS	251.1	O/S	20.61	20.83

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LM12839                    CSM ECS-CRYO TAB                                    0613

CTE 055:57:02     (          )    GET 055:54:53     (          )       SITE
-------LIFE SUPPORT--------                    -----PRIMARY COOLANT-----
GF3571  LM CABIN P       PSIA                | CF0019  ACCUM QTY PCT       34.4
CF0001  CABIN   P        PSIA     5.6        | CF0016  PUMP P     PSID     45.3
CF0012  SUIT    P        PSIA     4.13       | SF0260  RAD IN T      F     73.8
CF0003  SUIT      P    IN H2O    -1.8        Δ
CF0015  COMP      P    P PSID     0.27       Δ
CF0006  SURGE     P    P PSIA   889          | CF0020  RAD OUT T     F     35.2
        SURGE QTY          LB     3.9        | CF0181  EVAP IN T     F     45.7
   02  TK  1  CAP      P PSID    19          Δ CF0017  STEAM T       F     64.7
   02  TK  1  CAP      P PSID    17          Δ CF0034  STEAM P    PSIA       .161
                                               CF0018  EVAP OUT T    F     44.6
CF0036  02 MAN P         PSIA   108
CF0035  02 FLOW         LB/HR     0.178
                                               SF0266  RAD VLV 1/2          ONE
CF0008  SUIT T              F    50.5        | CF0157  GLY FLO LB/HR      215
CF0002  CABIN               F    65          | ----SECONDARY COOLANT----
CF0005  CO2 PP           MMHG     1.6        | CF0072  ACCUM QTY PCT       36.8
-----------H20------------                   | CF0070  PUMP P    PSID       9.3
CF0009  WASTE             PCT    28.9        | SF0262  RAD IN T     F      76.5
        WASTE              LB    14.9        | SF0263  RAD OUT T    F      45.1
CF0010  POTABLE           PCT   109.9        | CF0073  STEAM P   PSIA       .2460
        POTABLE            LB    39.1        | CF0071  EVAP OUT T   F      65.9
CF0460  URINE NOZ T         F   105          | CF0120  H20-RES   PSIA      26.2
CF0461  H2O NOZ T           F    78          | TOTAL FC CUR      AMPS
--------CRYO SUPPLY-------------------02-1------02-2-------H2-1-----------H2-2---
SC0037-38-39-40 P          PSIA      872        19       225.7(03-1)     235.1
SC0032-33-30-31 QTY         PCT       72.3      01.17      73.24           74.03
SC0041-42-43-44-T             F     -189        O/S       -417            -416
            QTY             LBS      251.1      O/S        20.61           20.83
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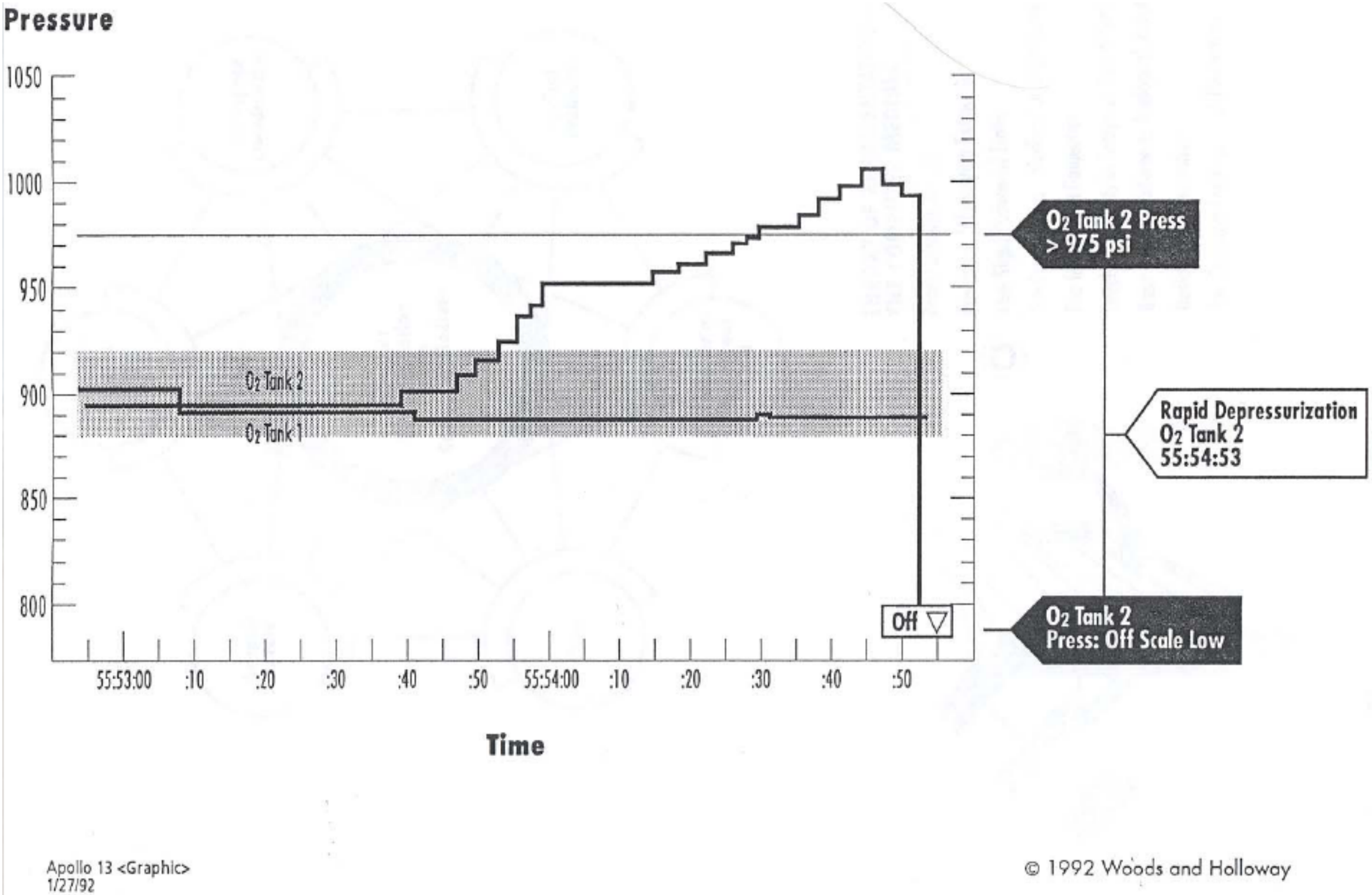
Another view…



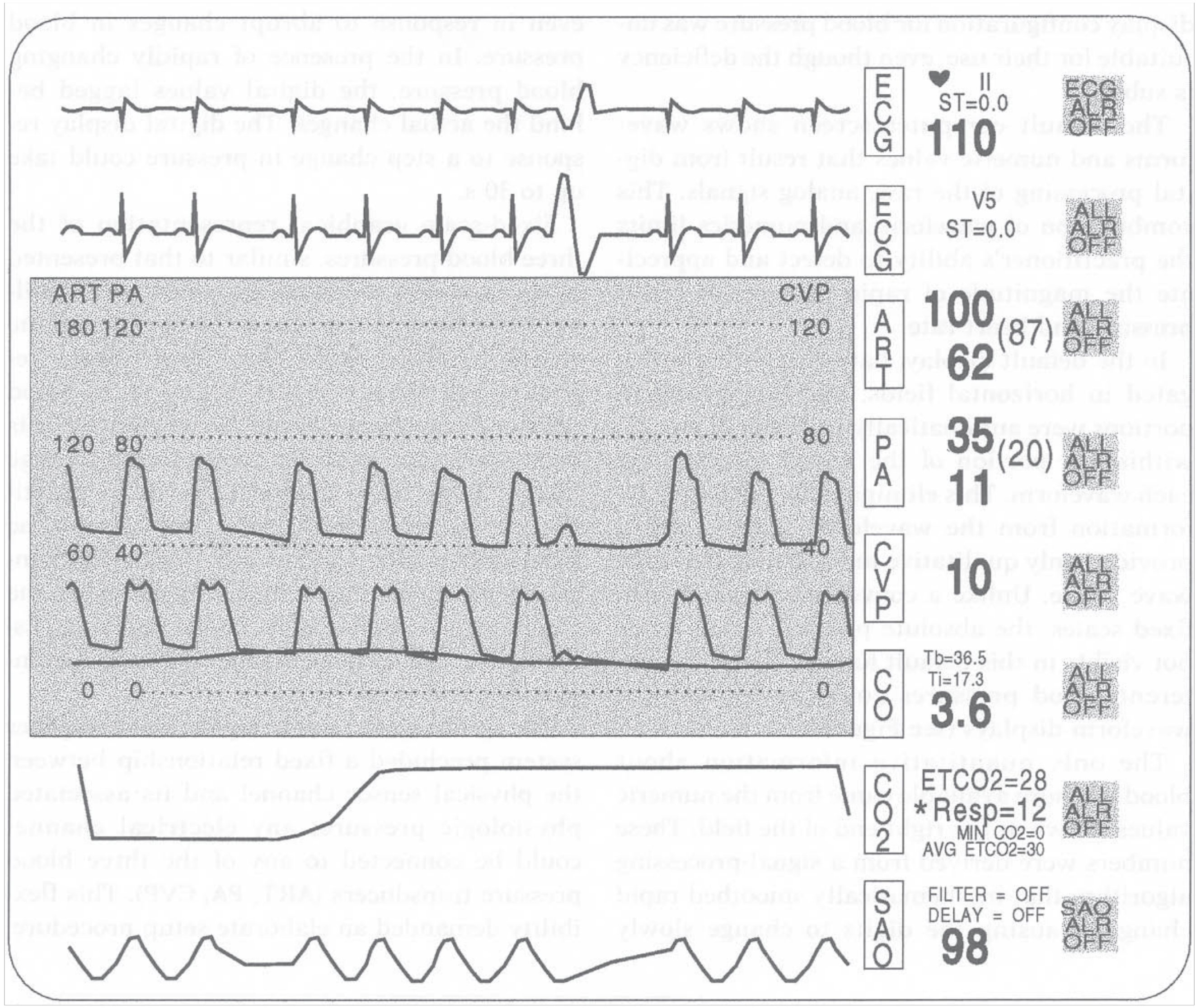
Representation design guidelines

1. Put data into context
   - Put a given datum into the context of related values
   - Collect and integrate data about important domain issues.
2. Highlight change and events – should help reveal dynamics of monitored process.
3. Highlight contrasts – should support observer recognition of contrasts – some departure from a reference or expected course.

Case study: Medical monitoring system [Cook and Woods]

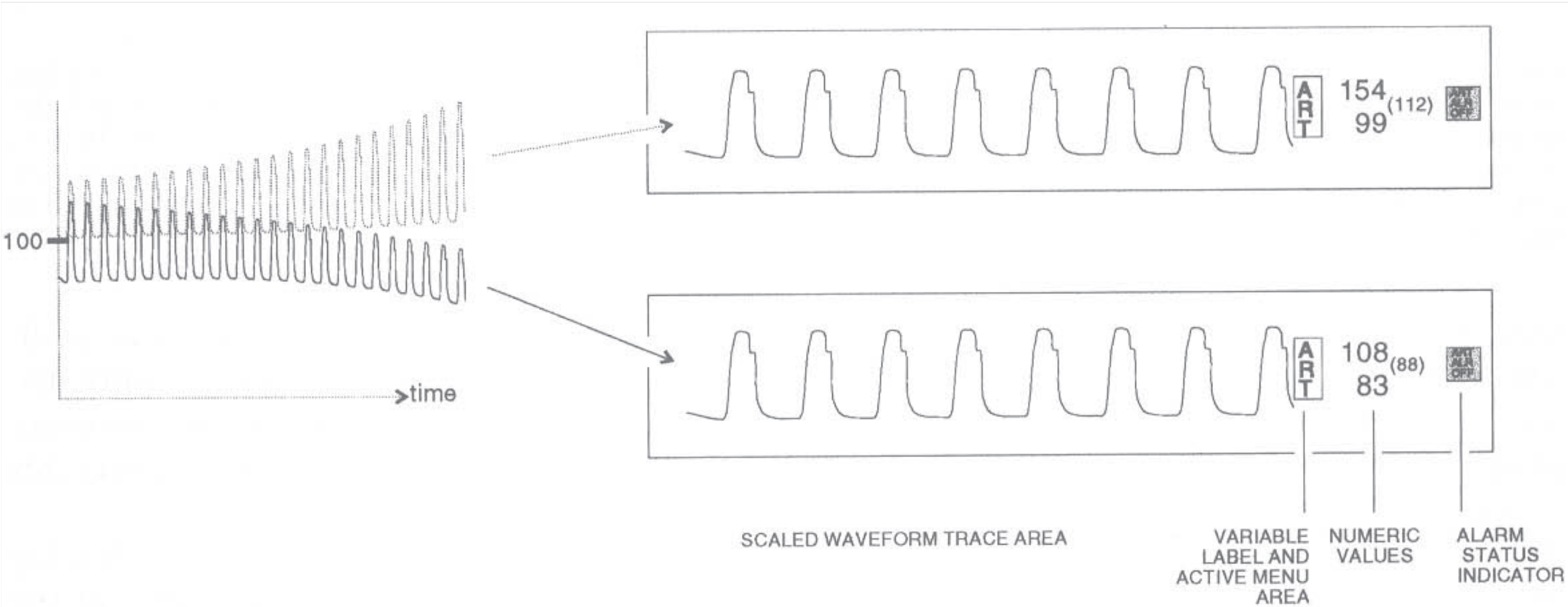
- Physiological monitoring system for use in cardiac anaesthesia.
- Single display with multiple windows and large space of menu options for manoeuvring among different representations, options and features.
- Many different views contain sensor data on the state of the monitored process (patient).
- Many different menus to access these views
- Each display will thus contain many different pieces of sensor data.

Blood pressure window



Visual Representations

- Default format for blood pressures is automatically scaled. Quantitative information from numeric values at right hand side. But these calculated as rolling average, smoothing rapid changes.



Work-arounds

- Practitioners resorted to “tricking” system into delivering desired display.
- Adapted physical interaction strategy to overcome problems with touch sensing.
- Conflict between wanting CO values and blood pressure values.
- Had to add additional steps to task of bringing up CO display temporarily, and quickly reverting to “normal” screen.

Keyhole property

- Property of virtual perceptual field of computer based display systems is viewport size is very small relative to the large size of the artificial display space or number of data displays that potentially could be examined.
- Proportion of total data that can be seen at the same time is small =>keyhole property.

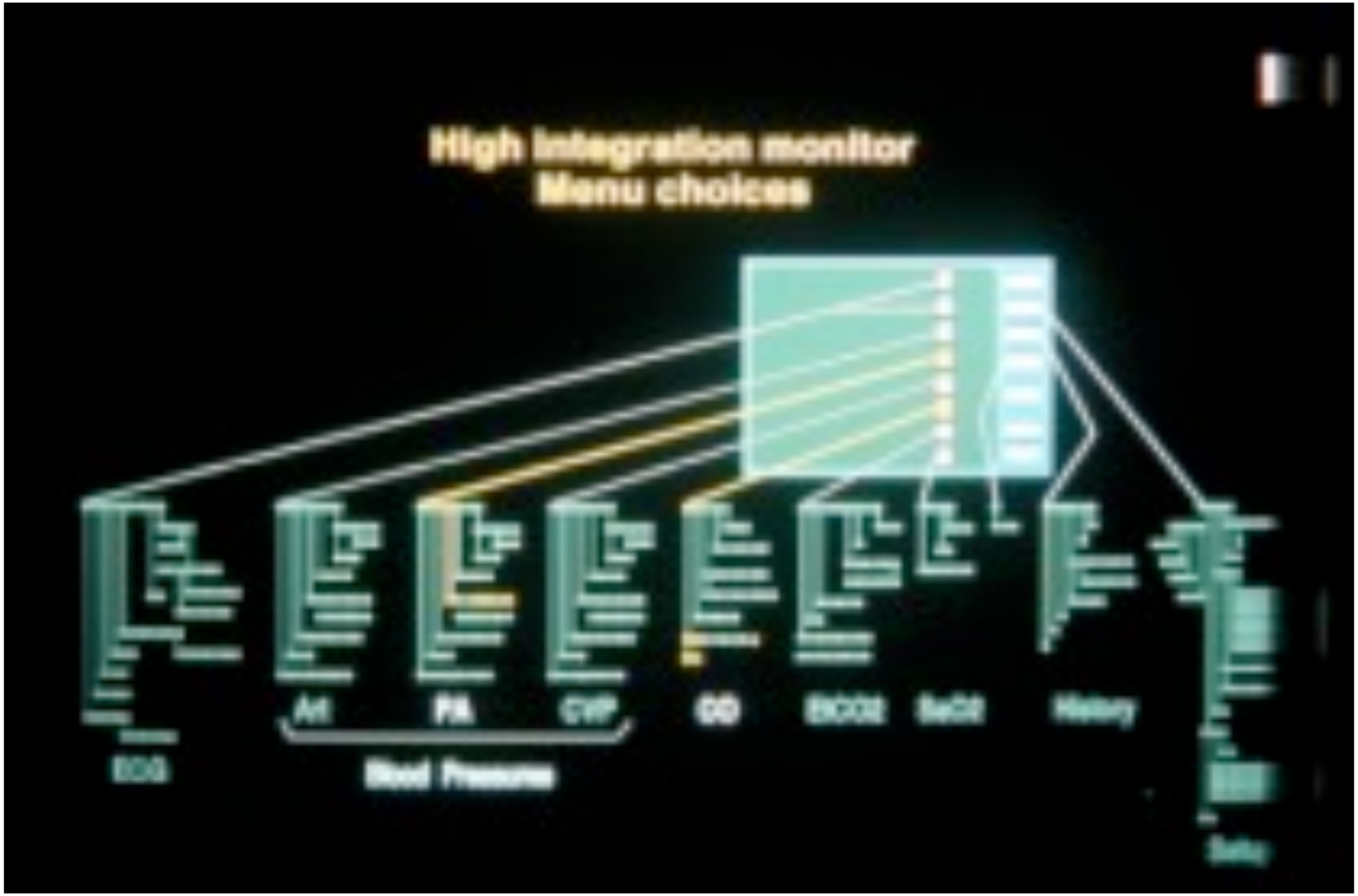
Diagnosis task

- “Abnormal” readings are flagged by the intelligent system.
- Assuming the operator sees that an event has occurred, all the practitioner knows is that parameter is abnormal.
- They do not know why the AI system considers the change important or interesting in the current context.
- Practitioners have to decide, what other data to examine to pursue event and anomaly.
- Decide where to look next through keyhole.
- Decide whether change is important in this situation.

Finding the data

- Should other events be investigated first? Does signal warrant interrupting ongoing lines of reasoning with regard to diagnosis or response selection?
- What other related data will support evaluations?
- Where do these data reside in the virtual field, and how to call up these displays?
- Does the display called into the viewport contain prompts to pertinent data, other displays or navigation commands?
- For each menu or display, practitioners must re-orient to the new view and search for the relevant item.

Options used over 3 months



Managing the display space

- By the time target data is found in the space, practitioners may have opened several windows.
- New task ->decluttering the workspace. If delayed, significant events may be missed.
- New task directs attention away from assessing the change in process state or evaluating how to respond.
- If extra information management burdens congregate at high-tempo high-criticality periods, impacts on practitioners ability to find right data at right time.

Serial access to data

- System very often forces serial access to highly inter-related data. Users must search step-by-step and datum by datum the state of the process, and manually integrate related data.
- More demands on memory, rather than less.
- Representation of monitored process on display underutilised as external memory.
- Knowing where to look next in the data space and extracting information across multiple views fundamental cognitive activity.
- Designs often neglect orienting cues that indicate whether something interesting may be going on in another part of the data space.

Generic system responses to errors

- Forcing functions
- Gag
- Warn
- Do nothing
- Self correct
- Let’s talk about it
- Teach me

Forcing functions

- A forcing function is an aspect of a design that prevents the user from taking an action without *consciously* considering information relevant to that action.
- It *forces* conscious attention upon something ("bringing to consciousness") and thus deliberately disrupts the efficient or automatised performance of a task.

Forcing functions

- User: Remove file "My-most-important-work."
  Computer: Are you certain you wish to remove the file "My-most-important-work"?
  User: Yes.
  Computer: Are you certain?
  User Yes, of course.
  Computer The file "My-most-important-work" has been removed.
  User: Oops!

Skills, Rules, Knowledge.

Skills level: is automatic, functions in normal operating environment. Much of this is not available to conscious thought, verbalisation, etc.

Jens Rasmussen

Rule-level: Behaviour becomes a conscious activity and is based on familiar rules — either dictated or acquired — this is for situations which are rarer but are known to occur and a rule for what to do can be provided.

Knowledge-level: Behaviour occurs at the knowledge level when there are no rules to inform the operator what to do. These conditions (usually emergencies) require some thought and reasoning about the state of the plant, based on the operator’s knowledge of the plant.

SRK framework

- Rasmussen's argument is that good design needs to support all three levels of operation, not just one.
- [One can note a social human factor here — if there are multiple operators, then at the knowledge level they may have different knowledge, which may give rise to conflict.]
- E.g. The Kegworth pilots were operating at all 3 levels. Some aspects of their behavior are automatic, for others they refer to rules and procedures, and for others they reason on the basis of their knowledge about the plane.

Planning

- The knowledge level implies a certain amount of planning activity, but some would argue that the degree to which people plan their actions is overstated — arguing that behaviour is situated (e.g. Suchman) in a context. In other words, they argue that we perceive the situation and decide what to do then, not (usually) on the basis of some pre-formed plan.
- One can do both — have a plan and allow the situation to change it (e.g. performing actions in a different order from that planned);
- Planning seems best related to Rasmussen's knowledge-level, whereas situated action is 'rule-level' behaviour. Again, these are not exclusive options - some people in some skills may function exclusively at one level, whilst others may switch between levels at high speed.

SRK and human error [J. Reason]

- **skill-based:** familiar, automatic procedural tasks
  - usually low-level, like knowing to type “ls” to list files
- **rule-based:** tasks approached by pattern-matching from a set of internal problem-solving rules:
  - if system state is failing at step 3, I should probably perform action A to fix it
- **knowledge-based:** tasks approached by reasoning from first principles
  - Rules and experience not enough.

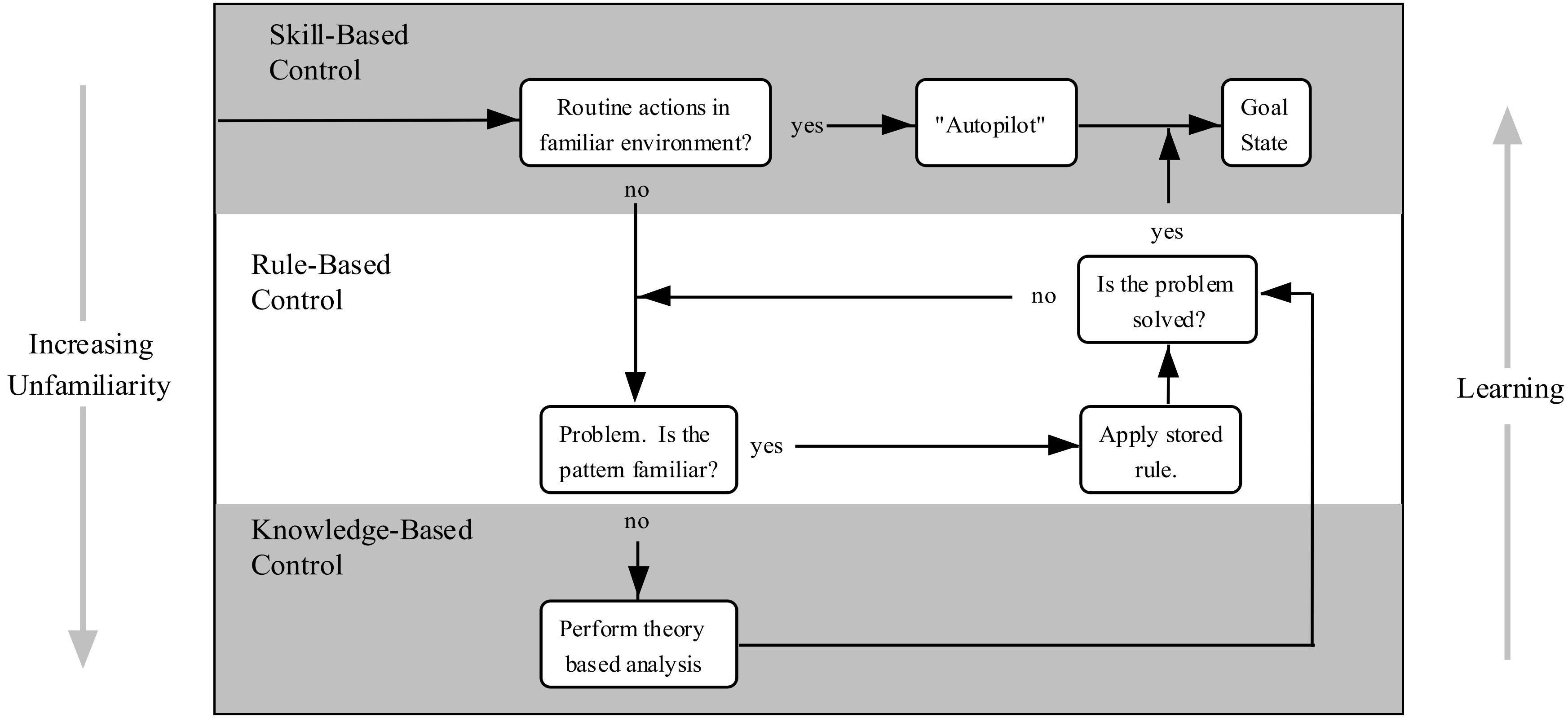
SRK and human error

- Errors can occur at each level
  - **skill-based:** slips and lapses
    - usually errors of inattention or misplaced attention
  - **rule-based:** mistakes
    - usually a result of picking an inappropriate rule
    - caused by misconstrued view of state, over-zealous pattern matching, frequency gambling, deficient rules
  - **knowledge-based:** mistakes
    - due to incomplete/inaccurate understanding of system, confirmation bias, overconfidence, cognitive strain, ...
- Errors can result from operating at wrong level
  - humans are reluctant to move from RB to KB level even if rules aren't working

Frequency of errors

- In raw frequencies, SB >> RB > KB
  - 61% of errors are at skill-based level
  - 27% of errors are at rule-based level
  - 11% of errors are at knowledge-based level
- humans perform vastly more SB tasks than RB, and vastly more RB than KB
  - so a given KB task is more likely to result in error than a given RB or SB task

Generic Error Modeling System



Adapted from Reason, J. Human Error. p. 64.

Skill-based slips.

- Did I do that?
- How did I get here?

- “There can be no doubt I raised the flaps instead of the U/C after take-off. I had no memory at all of doing this. Why would I do this potentially dangerous thing on an aircraft with which I was completely familiar? I have no idea: no sickness, no stress, nothing dramatic personally.”

CHIRP incident database

Rule based mistakes

- Information presented is underspecified
- Familiar but wrong procedures are used
- Procedures are mis-remembered or blended
- *In the Kegworth accident the engine failure was treated as an engine fire leading to a shutdown procedure which prevented recovery*

The trouble with automation…

Automation is not the cure for human error

- automation addresses the easy SB/RB tasks, leaving the complex KB tasks for the human
  - humans are ill-suited to KB tasks, especially under stress
- automation hinders understanding and mental modeling
  - decreases system visibility and increases complexity
  - operators don’t get hands-on control experience
  - rule-set for RB tasks and models for KB tasks are weak
- automation shifts the error source from operator errors to design errors
  - harder to detect/tolerate/fix design errors

Case study: China Airlines 006

- Encountered turbulence due to jetstream
- Engine no. 4 hung at low power
- Autopilot tried to keep the airplane level and on course by turning the control wheel to the left.
- Worked for several minutes but required the autopilot to turn the control wheel more and more to the left.
- Eventually the autopilot had turned the wheel to the maximum and the aircraft began to slowly roll to the right.

- Pilot concerned about decreasing airspeed.
- Set autopilot to drop nose, watching ASI.
- Eventually took control from autopilot.
- Unaware of the strong left wheel input the autopilot had been using, and also hadn't noticed the substantial right bank the plane had already rolled into.
- The plane had entered clouds and pilot could not orient himself by looking through the windows. The plane had rolled over and was in a steep dive, losing 10,000 feet in twenty seconds and reaching abnormally high speeds.
- The crew and passengers experienced enormous forces, reaching five *g*.
- Eventually regained control and levelled out.

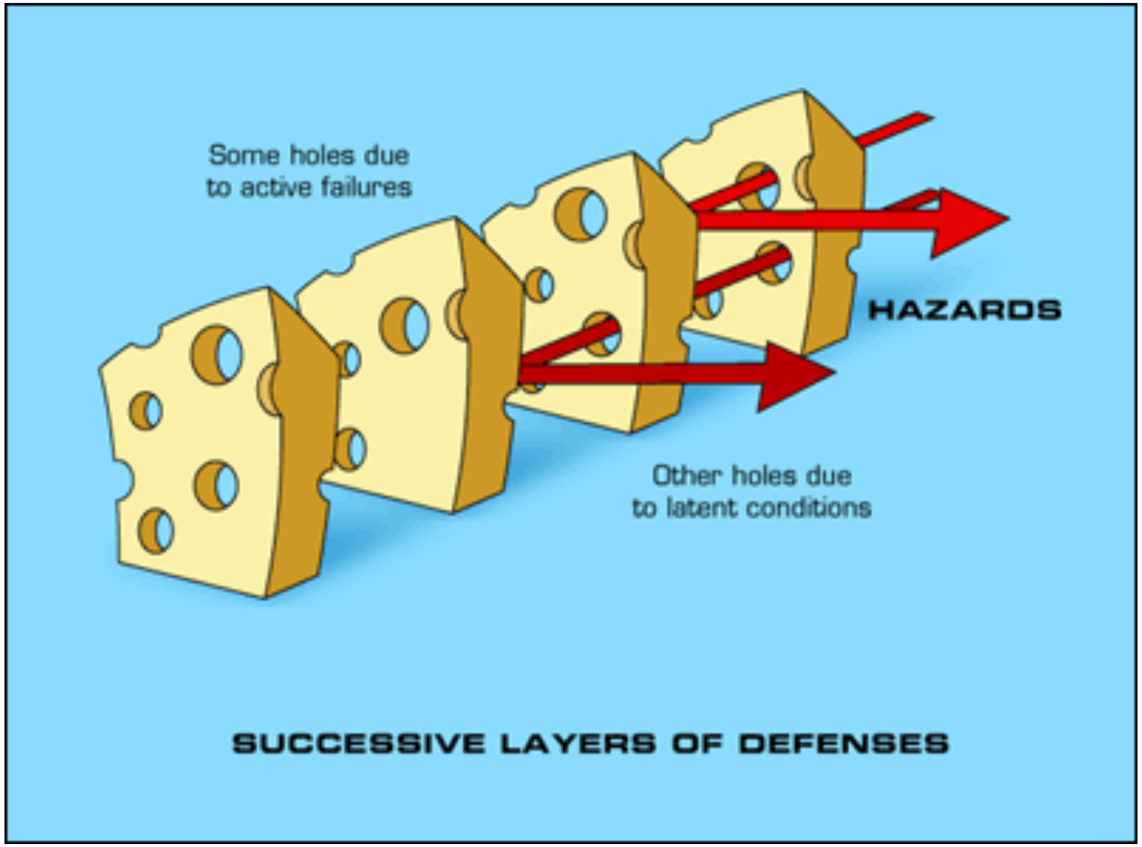
Errors and accidents: active error

- Reason defines error as a generic term to encompass those occasions in which a planned sequence of mental or physical activities fails to achive its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency.
- Sometimes a post-hoc classification of human performance.

Errors and accidents: latent failure

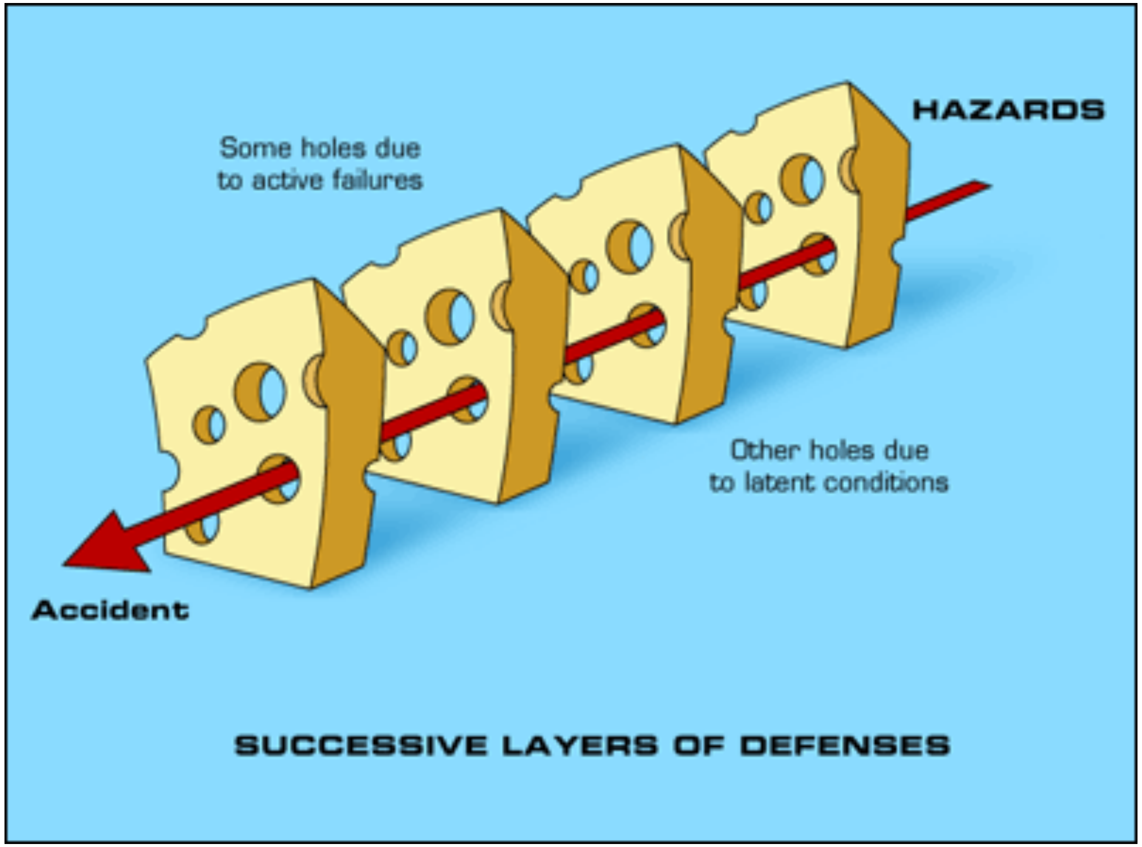
- Failures of organisation or design that contribute to the occurrence of errors or allowing them to cause harm.
- Human error is generally the result of factors beyond the control of those committing the errors
- Systems or processes that depend on perfect human performance are flawed.
- Often better to focus on *resilience* – design systems that can cope with error.

Reason's "Swiss Cheese" Model



From J. Reason, BMJ

Accidents



Active failures – immediate, usually shortlived impact.
Latent conditions – unworkable procedures, time pressure, poor designs.

High Reliability Organisations

"Perhaps the most important distinguishing feature of high reliability organisations is their collective preoccupation with the possibility of failure. They expect to make errors and train their workforce to recognise and recover them. They continually rehearse familiar scenarios of failure and strive hard to imagine novel ones. Instead of isolating failures, they generalise them. Instead of making local repairs, they look for system reforms." – J. Reason

Safety and Blame

“People make errors, which lead to accidents. Accidents lead to deaths. The standard solution is to blame the people involved. If we find out who made the errors and punish them, we solve the problem, right? Wrong. The problem is seldom the fault of an individual; it is the fault of the system. Change the people without changing the system and the problems will continue.”

Don Norman, the Design of Everyday Things

Safety and Blame

- Many critical domains have a “blame culture” where errors are punished severely.
- People reluctant to bring these consequences down on their co-workers, let alone themselves.
- Domains with a “safety culture” encourage comprehensive reporting of errors and near misses. Actions are taken to avoid them happening again. Widespread availability of data makes making detecting systemic problems and deciding on appropriate action much easier.
- Some people now using the term “Just culture”, to acknowledge that while blame cultures are counterproductive, accountability is required for cases where neglect or fitness to practice is an issue.

Designing for error

Reduce opportunities for error (Don Norman):

- Get good conceptual model to user by consistent design
- Design tasks to match human limits: working memory, problem solving abilities. Think about loss of activation.
- Make visible what the options are, and what are the consequences of actions
- Exploit natural mappings: between intentions and possible actions, actual state and what is perceived, …
- Use constraints to guide user to next action/decision
- Design for errors. Assume their occurrence. Plan for error recovery. Make it easy to reverse action and make hard to perform irreversible ones.
- When all else fails, standardize: ease of use more important, only standardize as last resort

Designing for error - feedback

- Appropriate feedback must be provided when the user performs some action. At the very minimum feedback must indicate that the users input has been received by the system.
- Provide feedback on what the impact of an action will be, before carrying it out (4,763,271 records will be deleted).
- Provide feedback on what the impact of an action has been, after carrying it out (4,763,271 records deleted).

Designing for error

- Acknowledge human behavior in system design:
  - interfaces should allow user to explore via experimentation
  - to help at KB level, provide tools do experiments without having to do them on high-risk irreversible plant. Or make system state always reversible.
  - provide feedback to increase error observability (RB level)
  - for RB, try to give more elaborate, integrated cues to avoid “strong-but-wrong” RB error
  - provide overview displays at edge of periphery to avoid attentional capture at SB level
  - simultaneously present data in forms useful for SB/RB/KB
  - provide external memory aids to help at KB level, including externalised representation of different options/models.