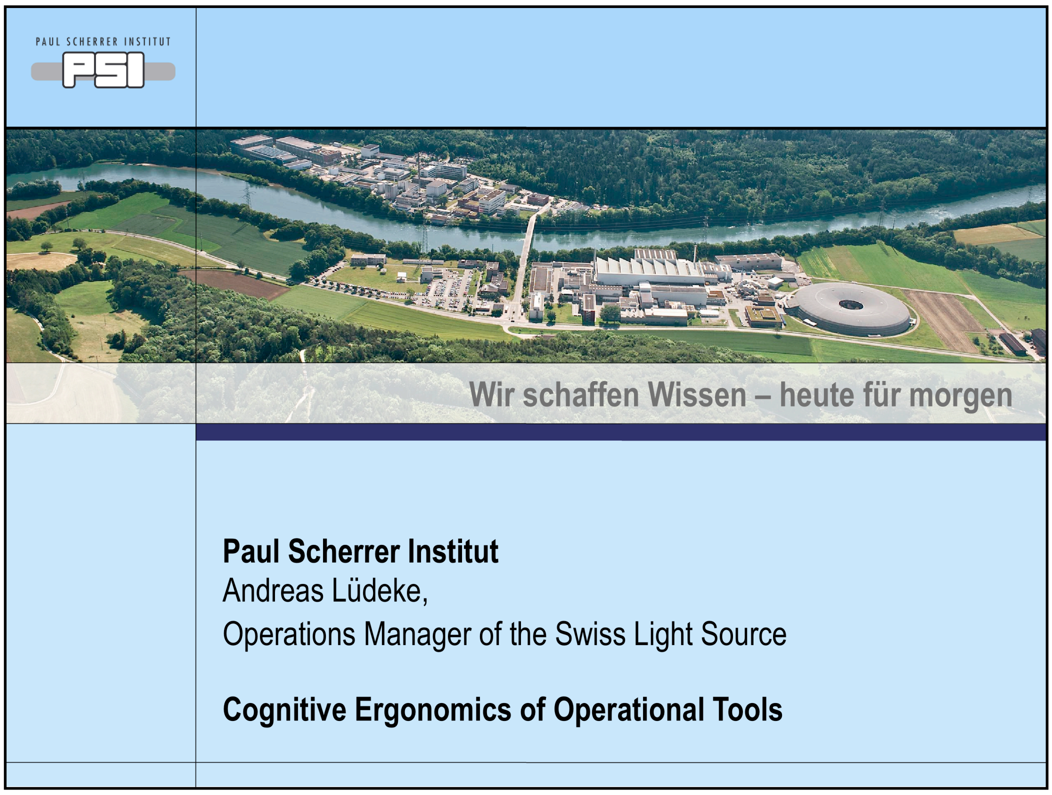
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PSI
Wir schaffen Wissen – heute für morgen

Paul Scherrer Institut
Andreas Lüdeke,
Operations Manager of the Swiss Light Source

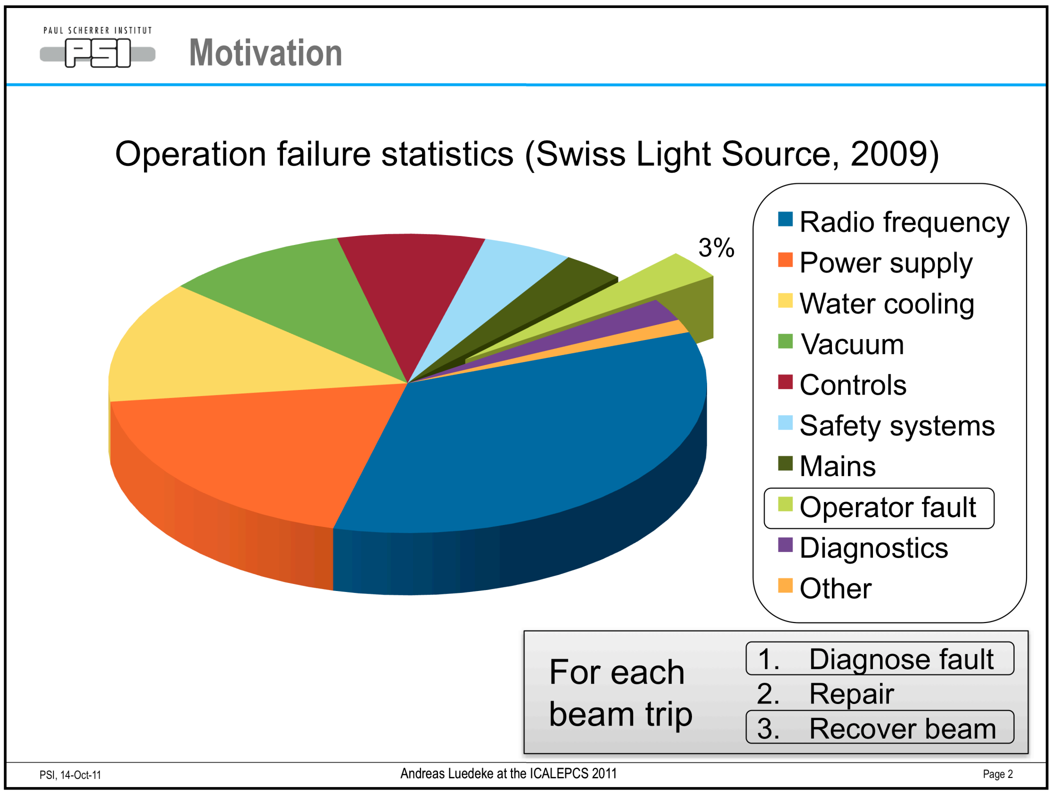
Cognitive Ergonomics of Operational Tools

What is an ergonomic tool?
- A "tool" is something to achieve a goal.
- It is "ergonomic" if it has been specifically optimized to be used by humans,
- taking our physical and cognitive limitations into account.

Think of a tennis rack. It is used to let a tennis ball fly with high speed in a chosen direction.
- Even an inexperienced player can achieve high ball velocities, much higher than by throwing
- Experienced players concentrate on goal (ball: which direction, how fast) he'll forget the rack!
- As long as you concentrate on the rack, you'll be a lousy player.
- And if the rack is broken, you'll get a direct acoustic feedback while using it.

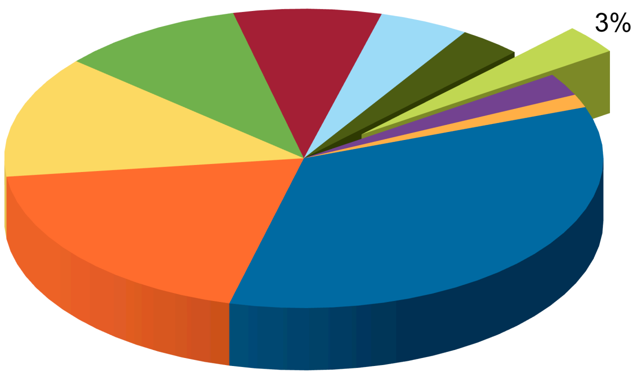
Today I'll give an introduction to the design of ergonomic tools for the operation of an accelerator facility I'm confident that operational tools based on these designs improve the availability of every machine.

I work now since about 20 years in the field of particle accelerators; since 10 years I am responsible for the operation of the Swiss Light Source. I can assure you that I have been exposed to many very ill designed operational interfaces. That of course qualifies me to give this talk. Another qualification of mine is my interest in cognitive science. You'll see that the limitation of our cognitive abilities are the source for the state-of-the-art user interface design rules, the foundation for ergonomic operational tools.



Motivation

Operation failure statistics (Swiss Light Source, 2009)



- 🟦 Radio frequency
- 🟧 Power supply
- 🟨 Water cooling
- 🟩 Vacuum
- 🟥 Controls
- 🟦 Safety systems
- 🟩 Mains
- 🟩 Operator fault
- 🟪 Diagnostics
- 🟧 Other

For each beam trip

1. Diagnose fault
2. Repair
3. Recover beam

PSI, 14-Oct-11 Andreas Luedeke at the ICALEPCS 2011 Page 2

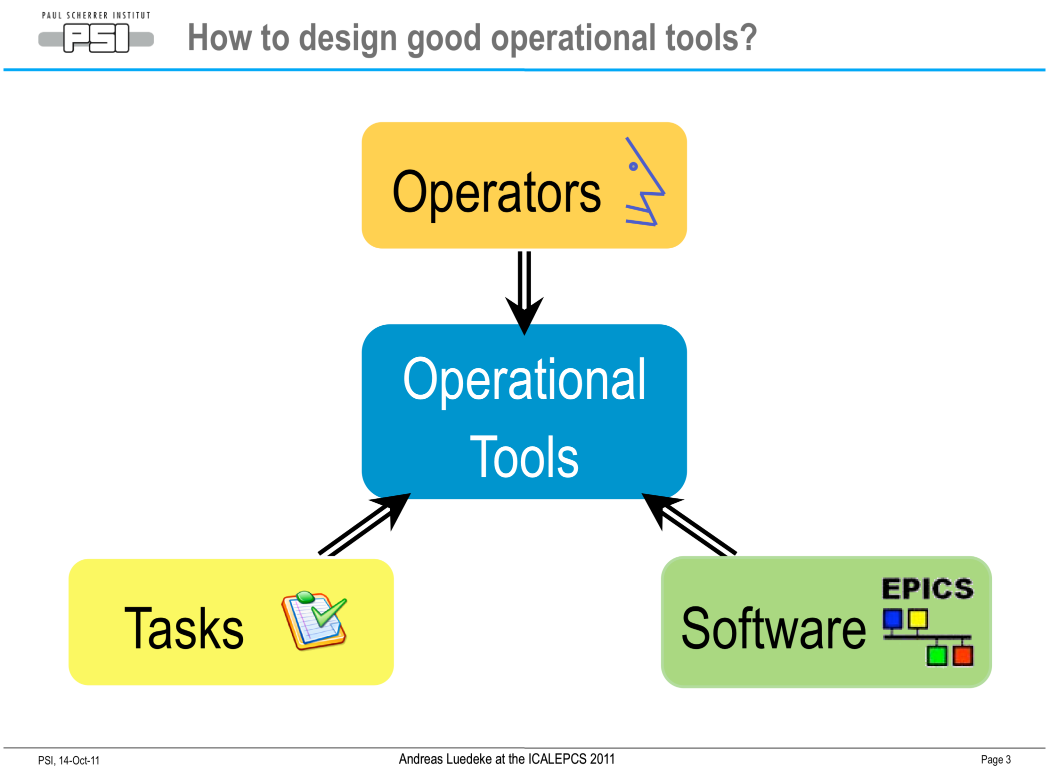
Why do we care for good operational tools?

My main objective as an operations manager is the beam availability at my facility.

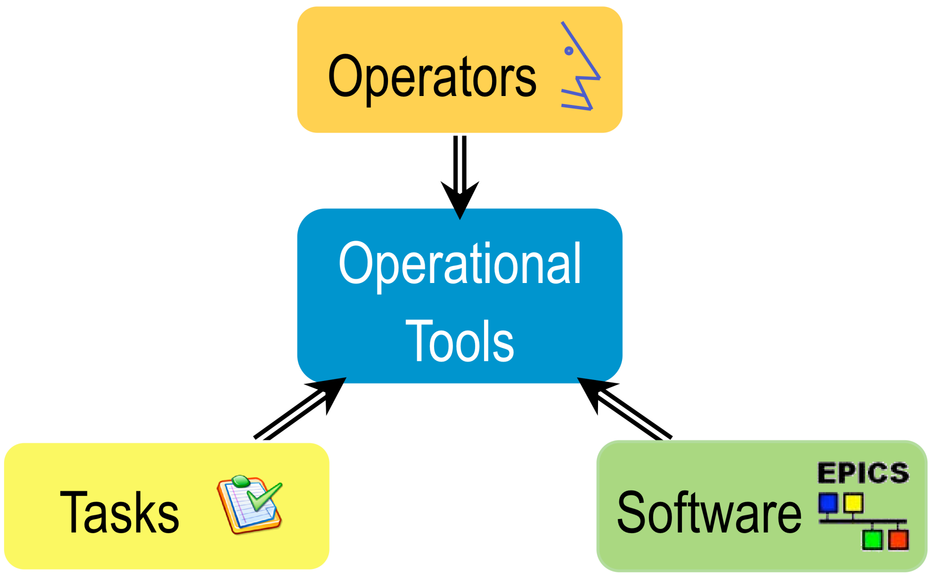
Every beam interruption is scrutinized for its causes. If we look at out beam failure statistics of 2009, we do not find any contribution from “bad operational tools”, or do we?

Well, about 3% of the outages were caused by faults of the operators. What does that mean? The only interaction of the operator with the accelerator is by his operational tools. If his action kills the beam, he was likely not able to properly predict the results of his actions. Or you could claim that his tools failed to communicate the risks of his actions to him in a timely manner.

For every beam trip, independent of the cause, the operators actions are divided in three steps: First he has to diagnose what has happened. If something prevents him from making beam again, he’ll need to organize the repair. And finally he’ll recover beam. For the first and the last step he’ll depend on his tools. If the time to repair is in the same order than the time to diagnose and recover, then of course good tools can save a significant amount of time and therefore contribute to improve the availability.



How to design good operational tools?



PSI, 14-Oct-11 Andreas Luedeke at the ICALEPCS 2011 Page 3

Now we know that we need to have good tools. But what is required to get them?

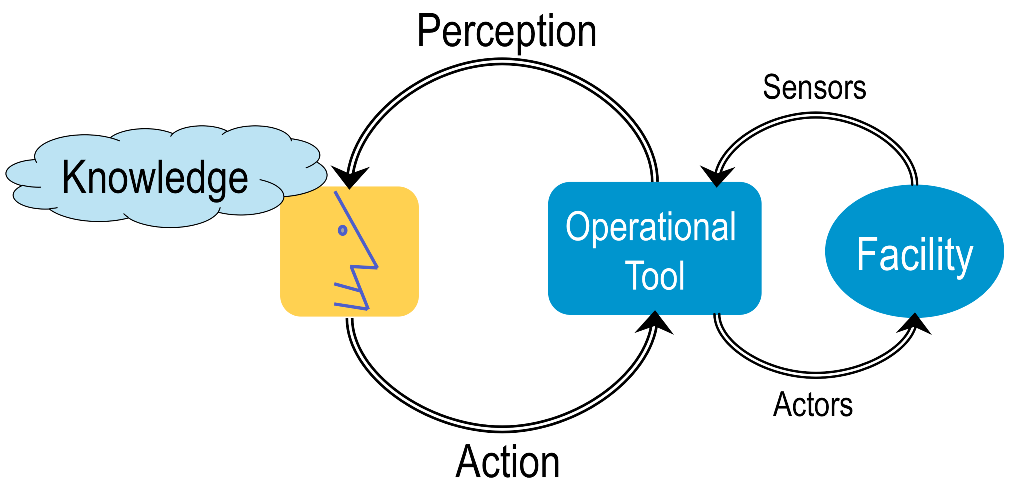
There are three aspects you need to understand to design a good operational tool.

- First you'll need to understand the needs of the operator, who will use your tools. This involves psychology, cognitive science and the theory of perception. Often neither the application developer nor his customer, the operation responsible are familiar with this area. We'll therefore focus on this aspect.

- Second you'll need to know the software of your control system to build good operational tools. That is normally among the core competence of the application developer. Many contributions of this conference are covering this topic, I'll skip it here.

- And third you'll need a thorough understanding of the operational tasks, because finally the tool should help to achieve specific goals. We will therefore look into techniques to improve our knowledge on the operational task, too.

Understand your Operators



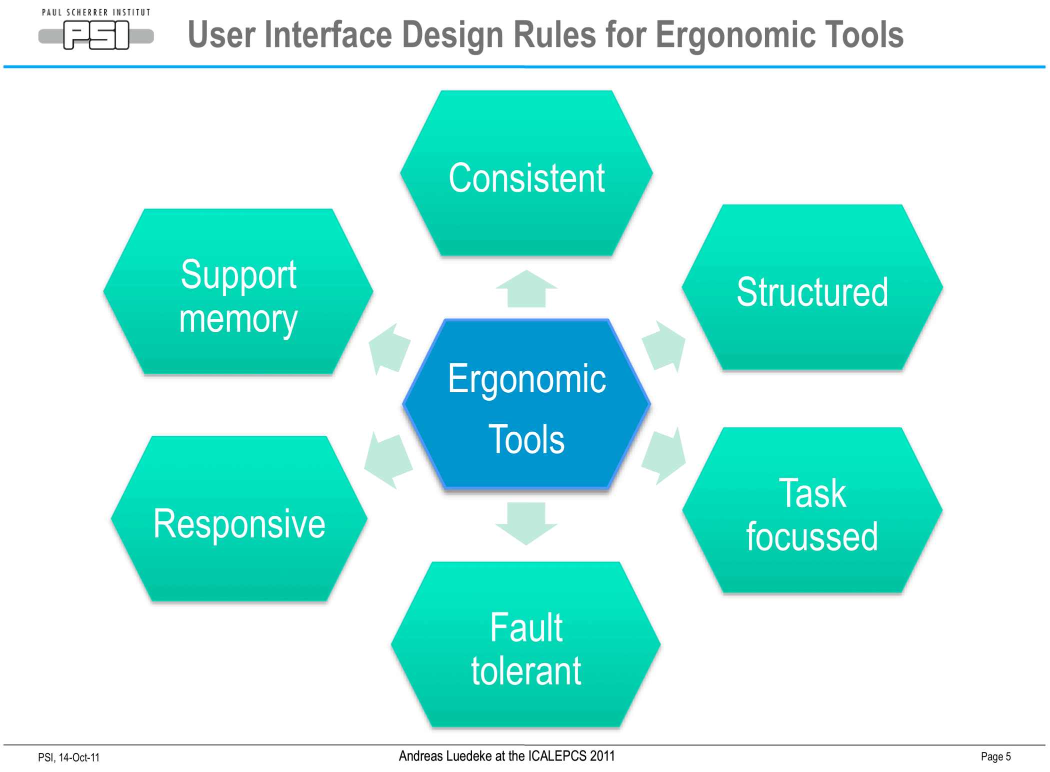
Often the application developer perfectly understands how his tool should interact with the facility;

But he does not have an appropriate model how the operator will interact with his tools.

We can use a simple model from interaction design: out operator will act on the tool, using the handles provided, like sliders for continuous control or buttons for discrete actions. His actions are driven by his goal and by his knowledge on how to achieve them. This knowledge can either be like a path, when he follows step-by-step instructions like a checklist. Or he has a mental map that allows him to find alternative routes to his goals. On his way to his goal he’ll perceive the information presented by his tool. He’ll interpret the information to find out if he’s approaching his goal or if he’s on the wrong path. The presented information can be a sharp picture to him, clearly showing his position on his chosen path. Or it can be a fuzzy, incomplete image, that needs to be completed by his interpretation.

We can learn from this model that the tool needs to provide the operator with the appropriate handles for his specific goals. The tools needs to present the information relevant to the task and in a way that is suitable for the operator to be perceived as a clear picture. And we should support the operator to build up the knowledge required to achieve the goals.

But how can we do that?



User Interface Design Rules for Ergonomic Tools

PSI, 14-Oct-11 Andreas Luedeke at the ICALEPCS 2011 Page 5

Fortunately the profession of human-computer interaction has already solved this problem for us. There are well established guidelines for user interfaces for the design of ergonomic tools. Even better, we don't necessarily need to understand the psychology behind them. Although often it'll help if we are better aware of the limitations of human perception, in order to better apply these rules to the design of operational tools.

The user interface design guidelines are formulated differently in the various reference publication for human-computer interaction. But the guidelines all share the same concepts, which I'll briefly introduce in the following slides with some examples. Your user interface needs to be:

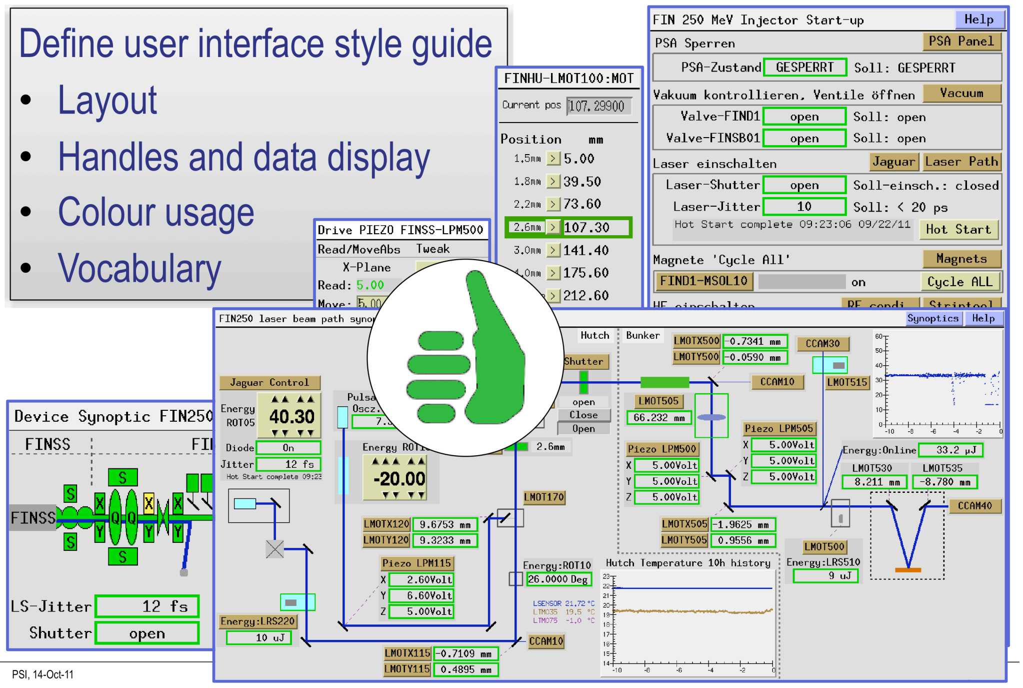
Consistent, visually structured, task focussed, fault tolerant, responsive and it should support the memory of the user.

All of these aspects of user interface design are important, the operator will suffer if your tool fails in any of them. But more important he'll likely do more errors and will be less confident to use the tools for the best performance of the machine.

Consistency and Structure by Style Guides

Define user interface style guide

- Layout
- Handles and data display
- Colour usage
- Vocabulary



Consistency and structure can be achieved by implementing a style guide for the design of the operational tools. You can define many aspects of the user interface: the general layout of the screens, like having a headline, where to place a help menu, or buttons to access related panels.

You may specify the type of handles to be used, their layout and how data should be displayed.

Colours should be defined and how they should be used. It is even useful to create a dictionary of the vocabulary to be used for buttons and labels to avoid ambiguity. Follow the simple rule “same name, same thing, different name, different thing”.

It is of course in most cases not sufficient to write such a style guide. You’ll need to train and support the application developers in how to adhere to it and you should control if they actually do.

But if you do that, you’ll get consistent and structured panels, and that will definitely make it easier for the operator to use them.

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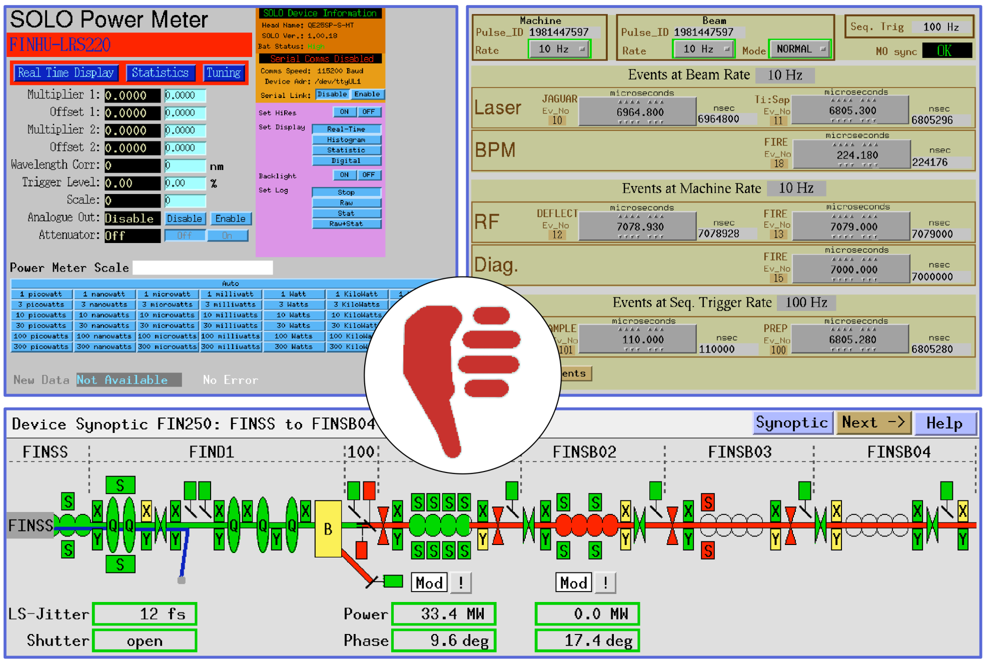
Consistency and Structure by Style Guides



SOLO Power Meter

FINHU-LRS220

Real Time Display | Statistics | Tuning

Multiplier 1:	0.0000	0.0000	
Offset 1:	0.0000	0.0000	
Multiplier 2:	0.0000	0.0000	
Offset 2:	0.0000	0.0000	
Wavelength Corr:	0	0	nm
Trigger Level:	0.00	0.00	%
Scale:	0	0	
Analogue Out:	Disable	Disable	Enable
Attenuator:	Off	Off	On

SOLO Device Information
Head Name: QE25SP-S-MT
SOLO Ver.: 1.00.18
Bat Status: High
Serial Comms Disabled
Comms Speed: 115200 Baud
Device Adr: /dev/ttyUL1
Serial Link: Disable Enable

Set HiRes ON OFF
Set Display Real-Time Histogram Statistic Digital
Backlight ON OFF
Set Log Stop Raw Stat Raw+Stat

Power Meter Scale

Auto

1 picowatt	1 nanowatt	1 microwatt	1 milliwatt	1 Watt	1 KiloWatt
3 picowatts	3 nanowatts	3 microwatts	3 milliwatts	3 Watts	3 KiloWatts
10 picowatts	10 nanowatts	10 microwatts	10 milliwatts	10 Watts	10 KiloWatts
30 picowatts	30 nanowatts	30 microwatts	30 milliwatts	30 Watts	30 KiloWatt
100 picowatts	100 nanowatts	100 microwatts	100 milliwatts	100 Watts	100 KiloWa
300 picowatts	300 nanowatts	300 microwatts	300 milliwatts	300 Watts	300 Kilow

New Data Not Available No Error

Machine	Beam	
Pulse_ID 1981447597	Pulse_ID 1981447597	Seq. Trig 100 Hz
Rate 10 Hz	Rate 10 Hz Mode NORMAL	MO sync OK

Events at Beam Rate 10 Hz

Laser	JAGUAR Ev_No 10	6964.800 microseconds	6964800 nsec	Ti:Sap Ev_No 11	6805.300 microseconds	6805296 nsec
BPM				FIRE Ev_No 18	224.180 microseconds	224176 nsec

Events at Machine Rate 10 Hz

RF	DEFLECT Ev_No 12	7078.930 microseconds	7078928 nsec	FIRE Ev_No 13	7079.000 microseconds	7079000 nsec
Diag.				FIRE Ev_No 15	7000.000 microseconds	7000000 nsec

Events at Seq. Trigger Rate 100 Hz

MPLE v_No 101	110.000 microseconds	110000 nsec	PREP Ev_No 100	6805.280 microseconds	6805280 nsec

ents

Device Synoptic FIN250: FINSS to FINSB04

Synoptic | Next -> | Help

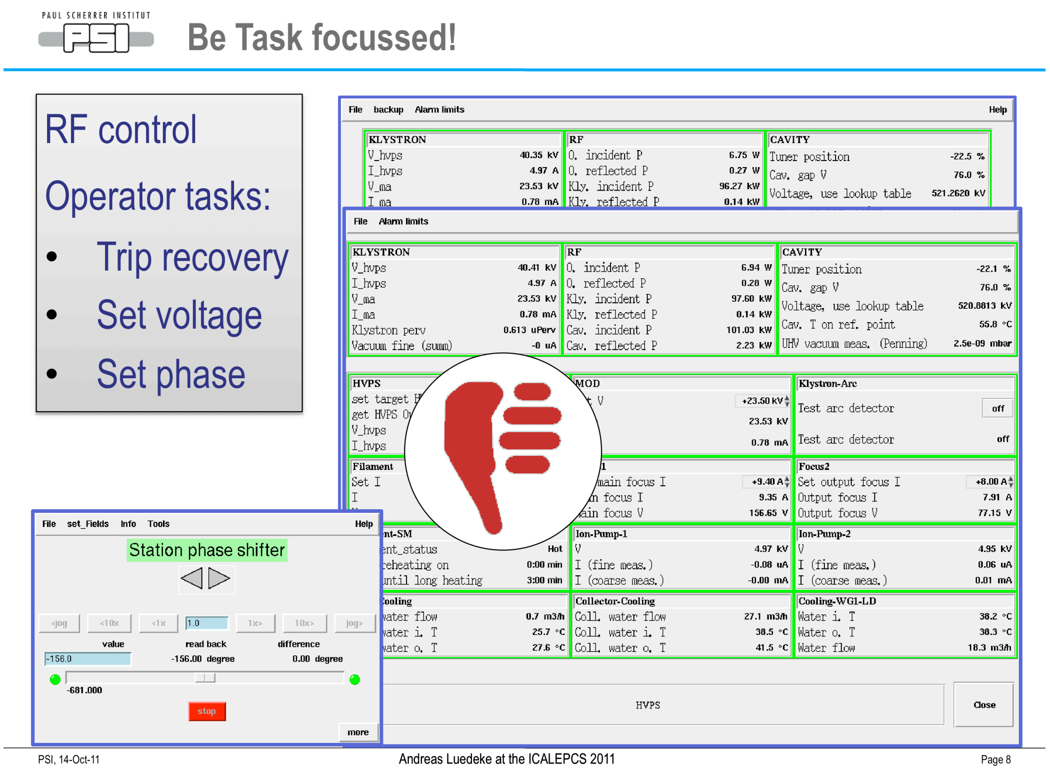
FINSS | FIND1 | 100 | FINSB02 | FINSB03 | FINSB04

LS-Jitter	12 fs		
Shutter	open		
		Power	33.4 MW	0.0 MW
		Phase	9.6 deg	17.4 deg

A funny thing about consistency is, that the very same tool can serve as a good or as a bad example, just depending on the context. Keep that in mind if you use tools from other facilities: they will likely not come according to your style guide. If you intent to keep them, then you should adapt them to your standard.

Consistency and structure are the most obvious aspects of the user interface design. For one it is obvious that inconsistent tools make it difficult to learn their usage. And it is clear that even a trained operator will be more likely to do wrong if his tools are not consistent. And it is a well obvious that structured information is easier to scan by human eyes for relevant data than unstructured text.

But those two aspects are obvious in a second sense, too: you can judge consistency and visual structure just by looking at the tool, without actually using them.



Be Task focussed!

RF control

Operator tasks:

- Trip recovery
- Set voltage
- Set phase

```
File  backup  Alarm limits                                                  Help

KLYSTRON                       RF                                CAVITY
V_hvps            40.35 kV     O. incident P          6.75 W     Tuner position                 -22.5 %
I_hvps             4.97 A      O. reflected P         0.27 W     Cav. gap V                      76.0 %
V_ma              23.53 kV     Kly. incident P       96.27 kW    Voltage, use lookup table  521.2620 kV
I_ma               0.78 mA     Kly. reflected P       0.14 kW
```

```
File  Alarm limits

KLYSTRON                       RF                                CAVITY
V_hvps            40.41 kV     O. incident P          6.94 W     Tuner position                 -22.1 %
I_hvps             4.97 A      O. reflected P         0.28 W     Cav. gap V                      76.0 %
V_ma              23.53 kV     Kly. incident P       97.60 kW    Voltage, use lookup table  520.8813 kV
I_ma               0.78 mA     Kly. reflected P       0.14 kW    Cav. T on ref. point           55.8 °C
Klystron perv    0.613 uPerv   Cav. incident P      101.03 kW    UHV vacuum meas. (Penning)  2.5e-09 mbar
Vacuum fine (summ)  -0 uA      Cav. reflected P       2.23 kW

HVPS                           MOD                               Klystron-Arc
set target H                   t V               +23.50 kV       Test arc detector                  off
get HVPS O                                        23.53 kV
V_hvps                                             0.78 mA       Test arc detector                  off
I_hvps

Filament                       1                                 Focus2
Set I                          main focus I        +9.40 A       Set output focus I              +8.00 A
I                              n focus I            9.35 A       Output focus I                   7.91 A
                               ain focus V        156.65 V       Output focus V                  77.15 V

nt-SM                          Ion-Pump-1                        Ion-Pump-2
ent_status            Hot      V                    4.97 kV      V                                4.95 kV
eheating on       0:00 min     I (fine meas.)      -0.08 uA      I (fine meas.)                   0.06 uA
until long heating 3:00 min    I (coarse meas.)    -0.00 mA      I (coarse meas.)                 0.01 mA

ooling                         Collector-Cooling                 Cooling-WG1-LD
water flow        0.7 m3/h     Coll. water flow    27.1 m3/h     Water i. T                      38.2 °C
water i. T       25.7 °C       Coll. water i. T    38.5 °C       Water o. T                      38.3 °C
water o. T       27.6 °C       Coll. water o. T    41.5 °C       Water flow                     18.3 m3/h

HVPS                                                             Close
```

```
File  set_Fields  Info  Tools                                   Help

                     Station phase shifter

<jog   <10x   <1x   [1.0]   1x>   10x>   jog>

        value              read back            difference
[-156.0]              -156.00 degree           0.00 degree

-681.000

                            stop
                                                           more
```

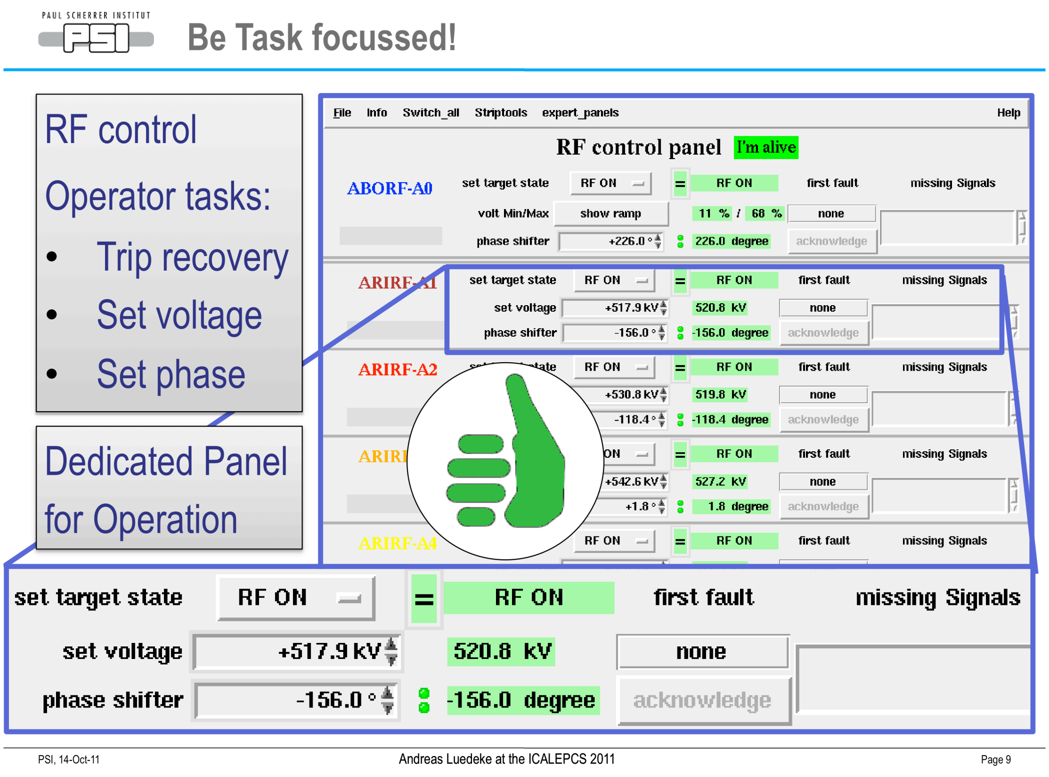
PSI, 14-Oct-11 Andreas Luedeke at the ICALEPCS 2011 Page 8

That is not the case with the other concepts.

Operational tools should be task focussed. What does that mean?

Consider an example, the operators task concerning the RF. We'll need to be able to switch the RF on after an interlock. Occasionally he'll need to adjust the set-voltage or the phase of an RF station. The RF control tool was delivered by the manufacturer of the RF amplifier. It provides access to all parameters available for RF tuning and shows all measurement provided. The main panel allows to recover the RF from a trip and a sub panel, one of many, allows to set the high voltage power supply. The phase tuner acts on the cavity and has an independent control panel.

This is exactly the opposite of a task focussed application. The task of the operator requires him to open several screens where the handles he needs are buried in a large number of other handles that he is not supposed to ever touch. The information he needs is hidden too, in between a huge amount of information irrelevant to his task. This all does not mean that the application is bad, it is just not the appropriate tool for the task of the operator. It is may be still appropriate for the tasks of an RF expert.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Be Task focussed!

RF control

Operator tasks:

- Trip recovery
- Set voltage
- Set phase

Dedicated Panel for Operation

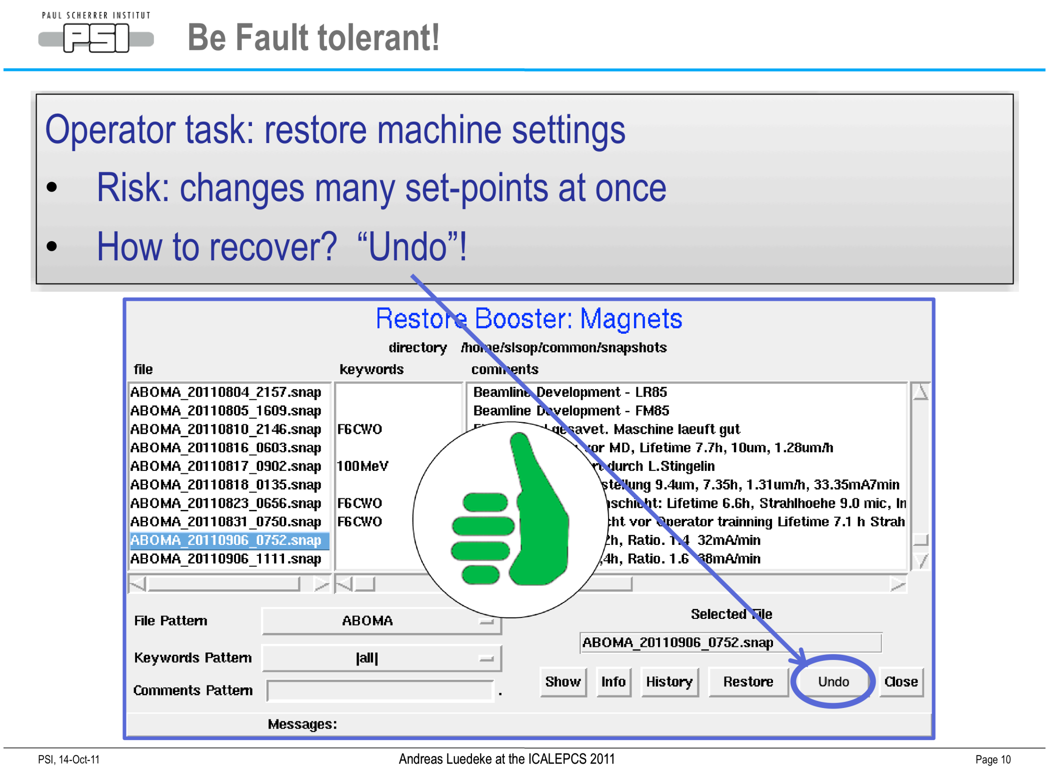
```
ABORF-A0   set target state  RF ON      =  RF ON              first fault   missing Signals
           volt Min/Max      show ramp     11 % / 68 %        none
           phase shifter     +226.0 °      226.0 degree       acknowledge
ARIRF-A1   set target state  RF ON      =  RF ON              first fault   missing Signals
           set voltage       +517.9 kV     520.8 kV           none
           phase shifter     -156.0 °      -156.0 degree      acknowledge
ARIRF-A2                     RF ON      =  RF ON              first fault   missing Signals
                             +530.8 kV     519.8 kV           none
                             -118.4 °      -118.4 degree      acknowledge
                             ON         =  RF ON              first fault   missing Signals
                             +542.6 kV     527.2 kV           none
                             +1.8 °        1.8 degree         acknowledge
ARIRF-A4                     RF ON      =  RF ON              first fault   missing Signals
```

```
set target state   RF ON       =  RF ON            first fault   missing Signals
set voltage        +517.9 kV      520.8 kV         none
phase shifter      -156.0 °       -156.0 degree    acknowledge
```

PSI, 14-Oct-11 Andreas Luedeke at the ICALEPCS 2011 Page 9

What it obviously needs is an application tailored to be used by the operator. This application should show all actions and information relevant for the operator tasks and nothing more.

This dedicated panel provides the handles to switch the state of the amplifier, to set the cavity voltage and to adjust the RF phase. It shows as well the status information relevant to the tasks.



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Be Fault tolerant!

Operator task: restore machine settings

- Risk: changes many set-points at once
- How to recover? “Undo”!

Restore Booster: Magnets

directory /home/slsop/common/snapshots

file	keywords	comments
ABOMA_20110804_2157.snap		Beamline Development - LR85
ABOMA_20110805_1609.snap		Beamline Development - FM85
ABOMA_20110810_2146.snap	F6CWO	[illegible] gesavet. Maschine laeuft gut
ABOMA_20110816_0603.snap		[illegible] vor MD, Lifetime 7.7h, 10um, 1.28um/h
ABOMA_20110817_0902.snap	100MeV	[illegible] durch L.Stingelin
ABOMA_20110818_0135.snap		[illegible] stellung 9.4um, 7.35h, 1.31um/h, 33.35mA7min
ABOMA_20110823_0656.snap	F6CWO	[illegible] schicht: Lifetime 6.6h, Strahlhoehe 9.0 mic, In
ABOMA_20110831_0750.snap	F6CWO	[illegible] cht vor Operator trainning Lifetime 7.1 h Strah
ABOMA_20110906_0752.snap		[illegible] 2h, Ratio. 1.4 32mA/min
ABOMA_20110906_1111.snap		[illegible] 4h, Ratio. 1.6 38mA/min

File Pattern: ABOMA

Keywords Pattern: |all|

Comments Pattern:

Selected File: ABOMA_20110906_0752.snap

Messages:

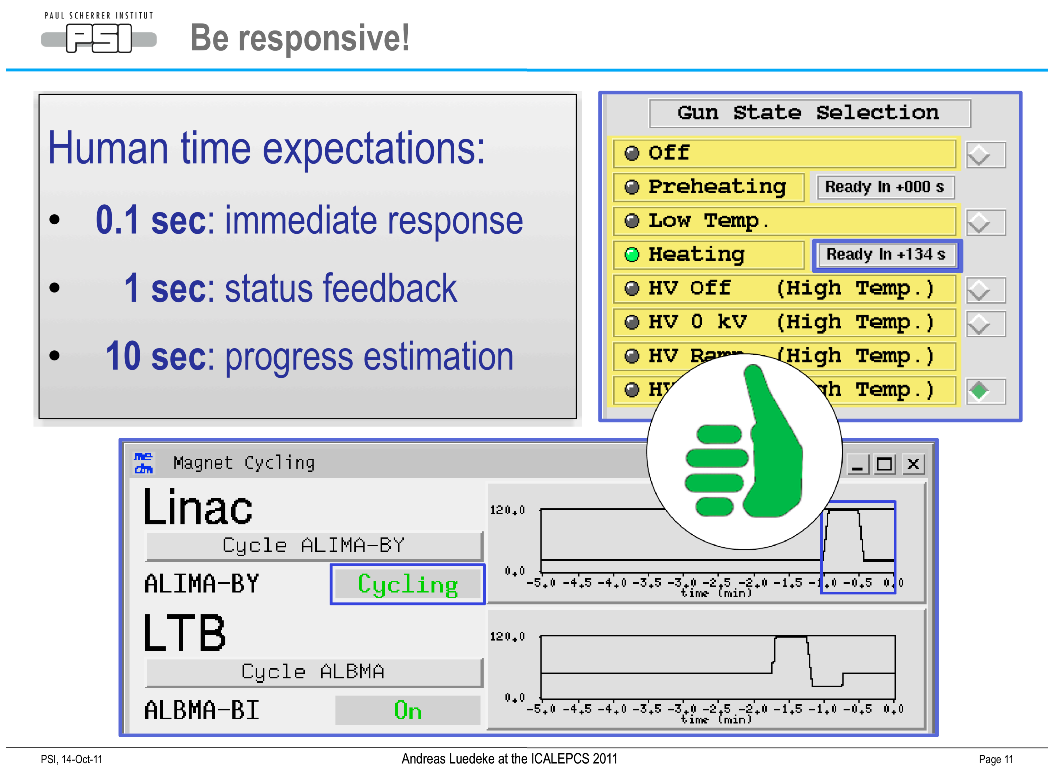
PSI, 14-Oct-11 Andreas Luedeke at the ICALEPCS 2011 Page 10

Ergonomic operational tools cannot fully prevent the operator from making mistakes. But they should make it hard for him to create severe problems and easy to recover from his mistakes.

An simple example is the SLS application to restore machine settings. If you restore a snapshot you’ll change dozens of machine parameters at once. You’ll have no guarantee that the restored snapshot will achieve a good machine state: it could have been a snapshot of a bad machine state, it could be corrupted, or it may does not work well with the current state of other parts of the machine.

If the effect of an action on the machine is severe, then it is a good idea to provide means to revert the action. Here an Undo button does the trick: the application saves a temporary snapshot, before it actually restores the selected one. If the restore does not lead to the desired result, the operator just presses Undo and the tool will restore the temporary snapshot to restore the previous machine state,

Providing means to recover from mistakes will increase the operators confidence in his tools. This will not just avoid severe problems, it’ll encourage him to use the tools more often to enhance the performance of the machine.



Be responsive!

Human time expectations:

- **0.1 sec**: immediate response
- **1 sec**: status feedback
- **10 sec**: progress estimation

Gun State Selection

- Off
- Preheating — Ready In +000 s
- Low Temp.
- Heating — Ready In +134 s
- HV Off (High Temp.)
- HV 0 kV (High Temp.)
- HV Ramp (High Temp.)
- HV (High Temp.)

Magnet Cycling

Linac

Cycle ALIMA-BY

ALIMA-BY Cycling

LTB

Cycle ALBMA

ALBMA-BI On

PSI, 14-Oct-11 | Andreas Luedeke at the ICALEPCS 2011 | Page 11

Responsiveness of software has proven to have a high impact on user satisfaction. More important an responsive application will tell the operator if his attention is currently required or not. Human time expectations range over several decades:

- Within a tenth of a second we expect an immediate response. That can just be a button to appear pressed. If it takes longer it will irritate us and if the application continue to show this behaviour it'll frustrates us, because it violates our sense of causality.

- In about one second we expect a feedback that something has actually happened, a status feedback. We need to be confident that our actions actually triggered the desired process.

- A process that takes longer than 10 seconds to complete should provide some kind of updating time estimate for the operator. This assures the operator that the process is still ongoing and releases his concentration to focus on other topics.

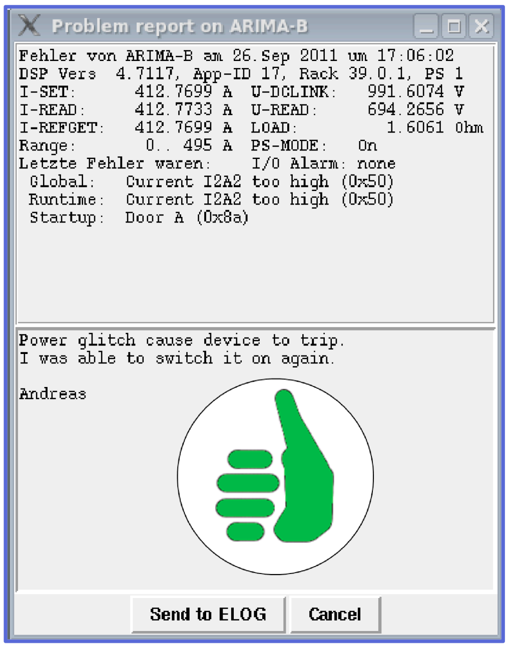
The application does not need to be fast in performing the task in order to be responsive.

The panel to start-up the SLS electron source for example just displays the remaining heating time of the cathode in seconds. It cannot do anything to accelerate the process, but it can clearly tell the operator when the process will be finished, to set him free to do other things until then.

An even simpler implementation of responsiveness has the application to standardize the magnetic fields with the power supplies. It shows two types of information: the status of the process, where "Cycling" indicates that it is still ongoing, and the read back of the magnet current, that tells the operator that the process is really still acting on the power supply and at the same time allows the operator to estimate the remaining time for the process.

Support Operators Memory!

- Consistency & structure
  - Tool headlines
  - Link related tools
  - Visibility of choices
- Checklists
- Gather relevant data
  - Automate task flow



```
Fehler von ARIMA-B am 26.Sep 2011 um 17:06:02
DSP Vers  4.7117, App-ID 17, Rack 39.0.1, PS 1
I-SET:      412.7699 A  U-DCLINK:   991.6074 V
I-READ:     412.7733 A  U-READ:     694.2656 V
I-REFGET:   412.7699 A  LOAD:         1.6061 Ohm
Range:        0.. 495 A  PS-MODE:   On
Letzte Fehler waren:    I/O Alarm: none
 Global:   Current I2A2 too high (0x50)
 Runtime:  Current I2A2 too high (0x50)
 Startup:  Door A (0x8a)
```

```
Power glitch cause device to trip.
I was able to switch it on again.

Andreas
```

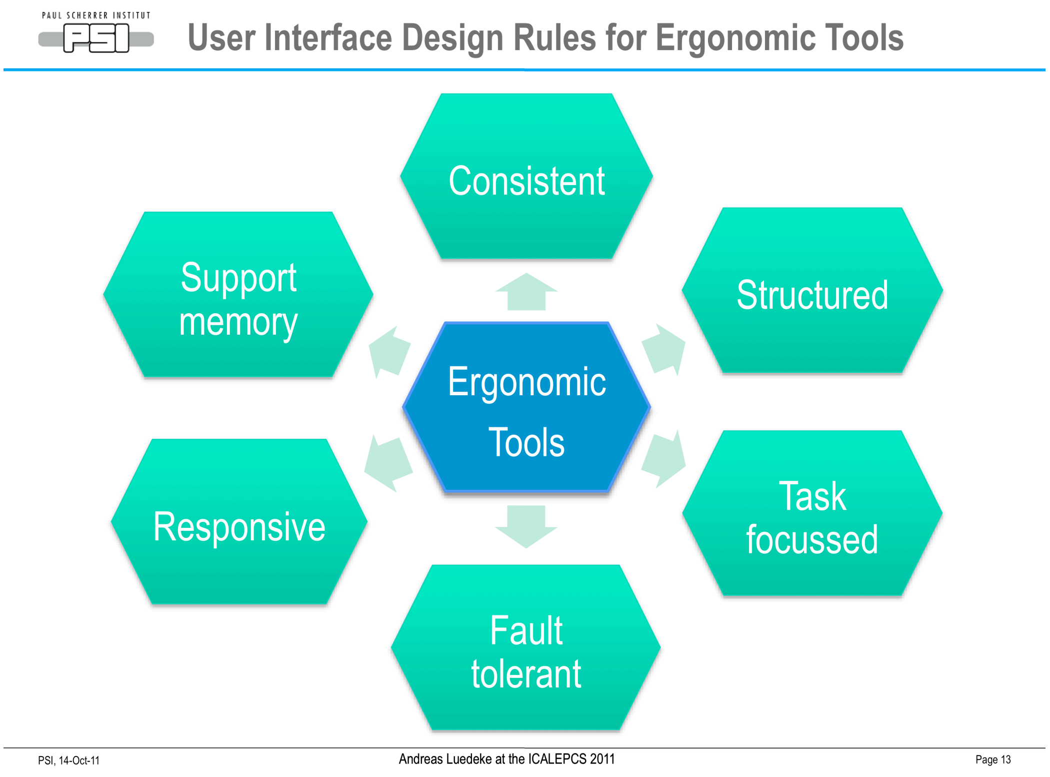
Consistency and structure is already a good measure to support the operators memory. The operator deals with hundreds of screens, a headline in each to indicate what they are for is appreciated. He’ll sometimes not find the correct screen immediately, therefore links to tools that support similar tasks are often useful. It is much easier to recognize the right action from a menu, than to recall it from the memory; if the number of choices is limited to the relevant it will make it even easier.

It is useful to provide checklists for long procedure: what needs to be done and what has been achieved. You can either integrate them into your logbook or you can provide checklist like applications.

The tools should gather the task relevant information for you, not just to display it.

For example a tool that allows you to recover from a failure should do the systematic part of the failure reporting for you.

Do not rely on the operator to document the failure from his memory. Here we see the application to diagnose a magnet power supply trip. The application allows to create a trouble report that can be saved to the electronic logbook. The logbook will e-mail the information to the power supply group for their power supply failure tracking. This saves time for the operator and assures that the failure reports will contain complete and consistent information.



User Interface Design Rules for Ergonomic Tools

Consistent
Support memory
Structured
Ergonomic Tools
Responsive
Task focussed
Fault tolerant

PSI, 14-Oct-11 Andreas Luedeke at the ICALEPCS 2011 Page 13

If we succeed to make our tools according to these design guidelines, we will have happy operators and improve the beam availability and performance.

But how do we know that we succeed?

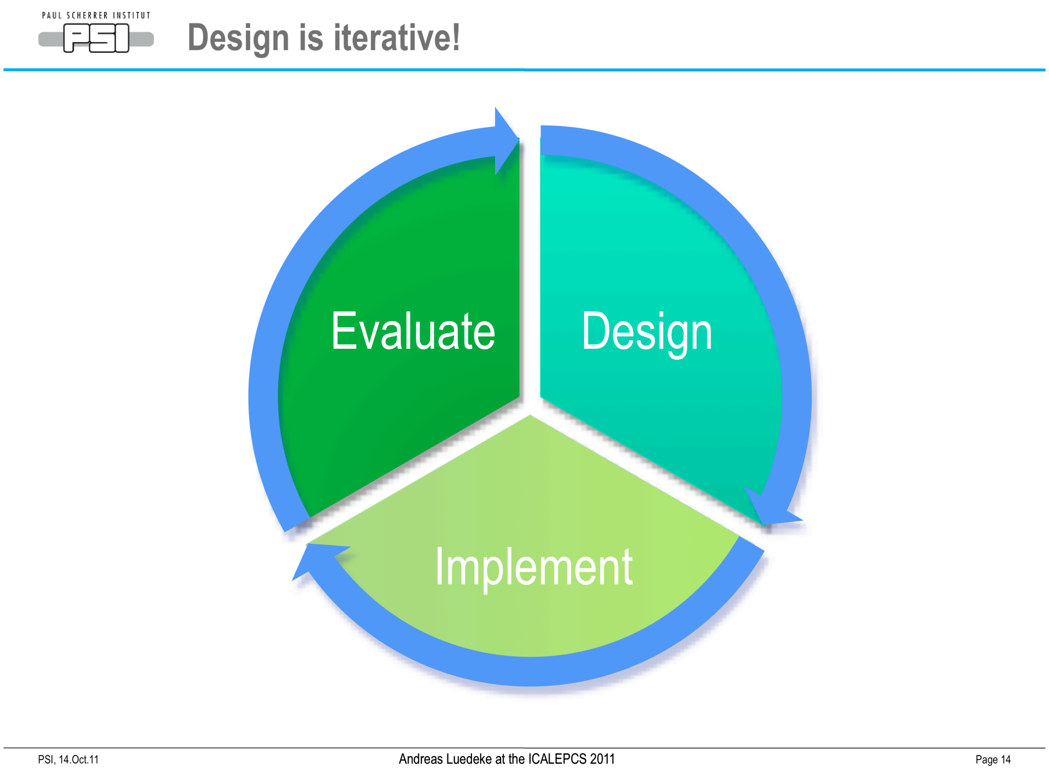
The problem with these design guidelines is, that they are just guidelines:

Often it will be still difficult to determine, how they can be properly applied to a specific problem.

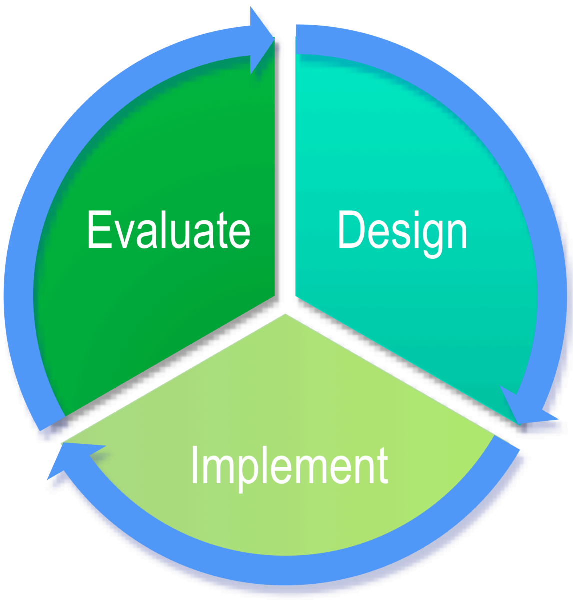
Sometimes they may even contradict each other for an application.

In addition the operators are maybe similar compared to the humans in total, but they still may disagree when it comes to what is useful in an application and what is useless.

What can we do about it?



Design is iterative!



PSI, 14.Oct.11 Andreas Luedeke at the ICALEPCS 2011 Page 14

Again human-computer interaction tells us the right solution.

Although in this case we can as well just use common sense:

When you design a tool to be used by humans you'll best go for an iterative design.

That means you'll design the tool to the best of your knowledge,

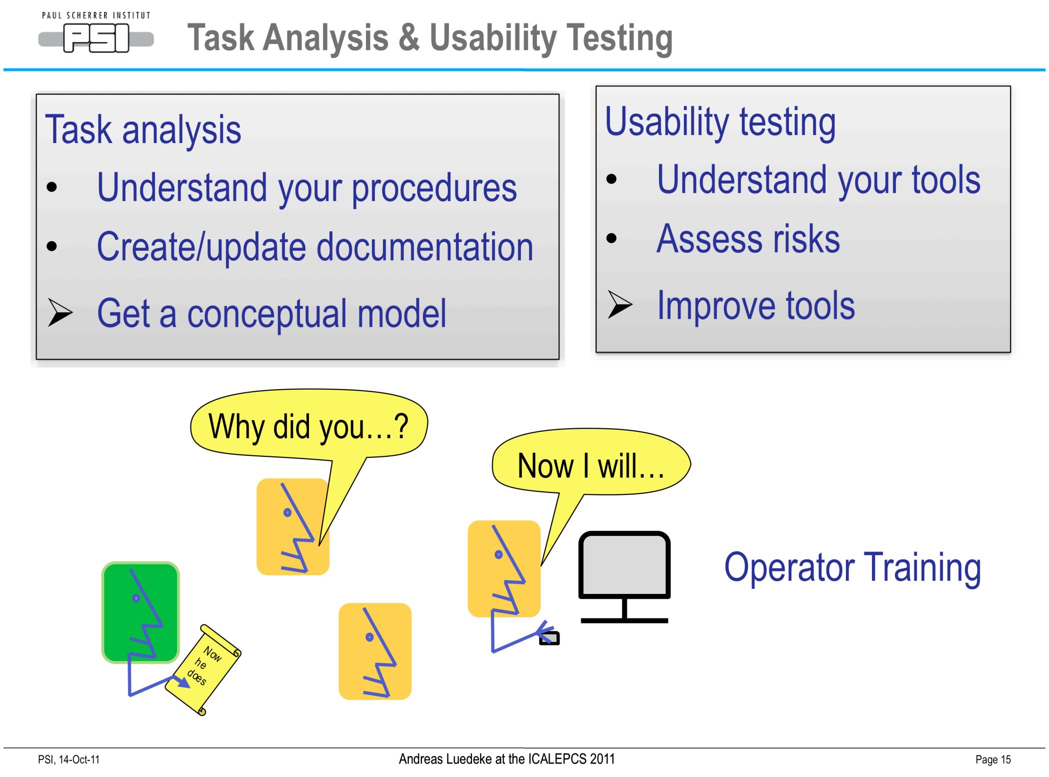
You'll implement it according to your design and then

You'll evaluate the implementation.

The results of your evaluation will tell you, what should be re-designed and the circle continues.

In human-computer interaction it is stated that this process ends either if you run out of time or out of resources. For an accelerator facility it may continues until the end of the operation of the facility.

But how to evaluate?



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Task Analysis & Usability Testing

Task analysis
- Understand your procedures
- Create/update documentation
- ➢ Get a conceptual model

Usability testing
- Understand your tools
- Assess risks
- ➢ Improve tools

Why did you…?

Now I will…

Now he does

Operator Training

PSI, 14-Oct-11 Andreas Luedeke at the ICALEPCS 2011 Page 15

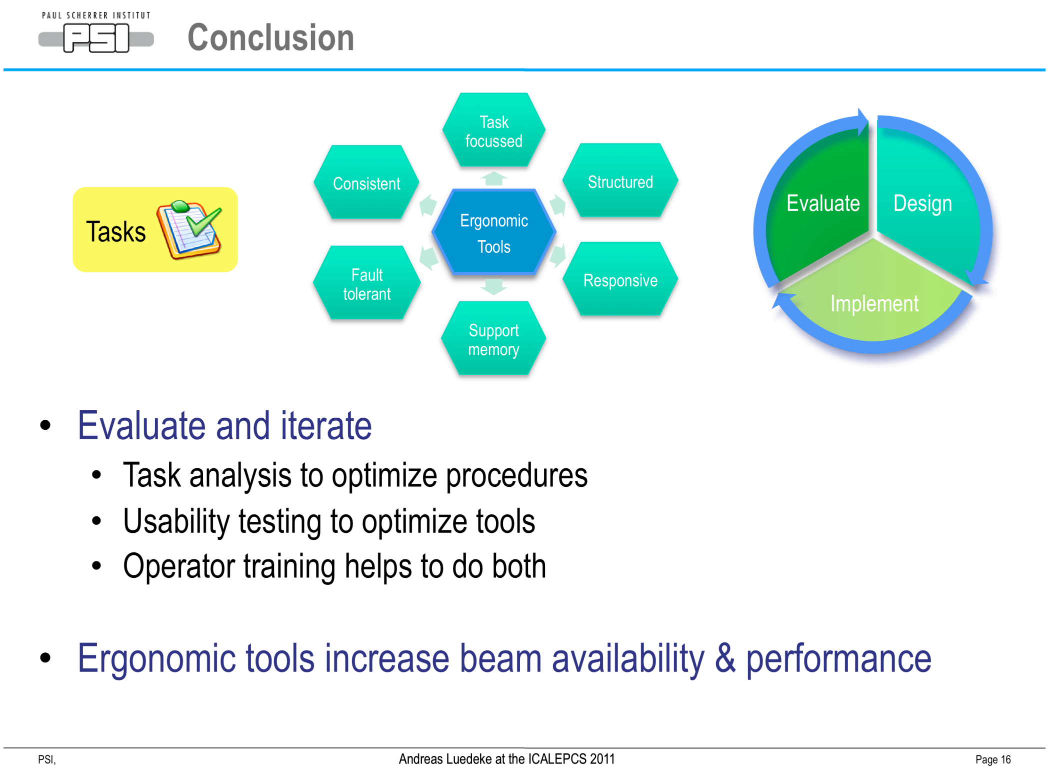
Task analysis and usability testing are two well established techniques to do exactly that.

In task analysis you try to understand your procedures. It has been developed primarily to create documentation, but it can be used to develop a conceptual model of the operation of your accelerator. That is an idealized view on how operation should work: what are the actions, what devices are involved and what are the relations between the action and the devices. A conceptual model should be simple and focussed on the tasks of the operator.

Usability testing has the goal to understand your tools. It allows you to asses risks in the usage of the tools and shows how they can be improved.

Both methods require you to observe the operator performing his tasks, while he is watched and somebody's writing down what he's doing. This is called "think-aloud" technique and it is useful to have other operators watching and asking questions, since that will reveal more of what the operator thinks what he's doing while he's using his tools. Does this sound familiar to you? Yes, we call it "operator training" at the Swiss Light Source. Once or twice a month we reserve 90 minutes beam time to do hands-on training with the operator: creating real randomized machine problems on demand from a "sabotage" applications. While one operator is assigned to fix the problem, several others are watching. His duty is to diagnose the problems, fix them and to recover beam. He has to explain what he is doing or attempts to do and to document everything. While the primary goal is to train the operator in failure analysis and beam recovery, it serves at the same time for a task analysis and for usability testing.

This has been proven very useful in the past years to identify risks in our operational tools and to improve their ergonomics.



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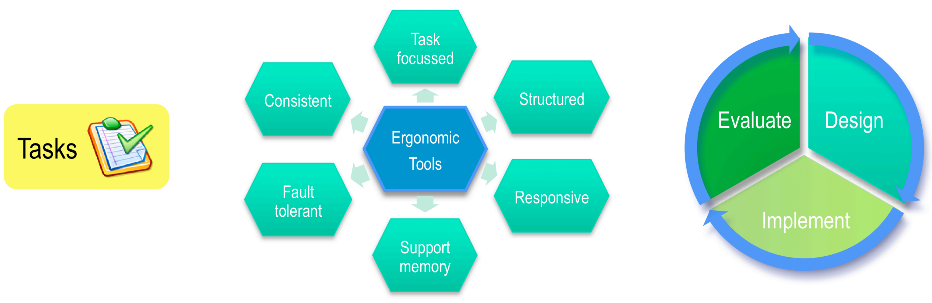
Conclusion



- Evaluate and iterate
  - Task analysis to optimize procedures
  - Usability testing to optimize tools
  - Operator training helps to do both
- Ergonomic tools increase beam availability & performance

References

Books to start with:

- J. Johnson, “Designing with the mind in mind: simple guide to understanding user interface design rules”, Amsterdam, Elsevier/Morgan Kaufmann Publishers, 2010.
- B. Shneiderman and C. Plaisant, “Designing the user interface: strategies for effective human-computer interaction”, 5th ed., Boston, Mass., Addison-Wesley, 2010.