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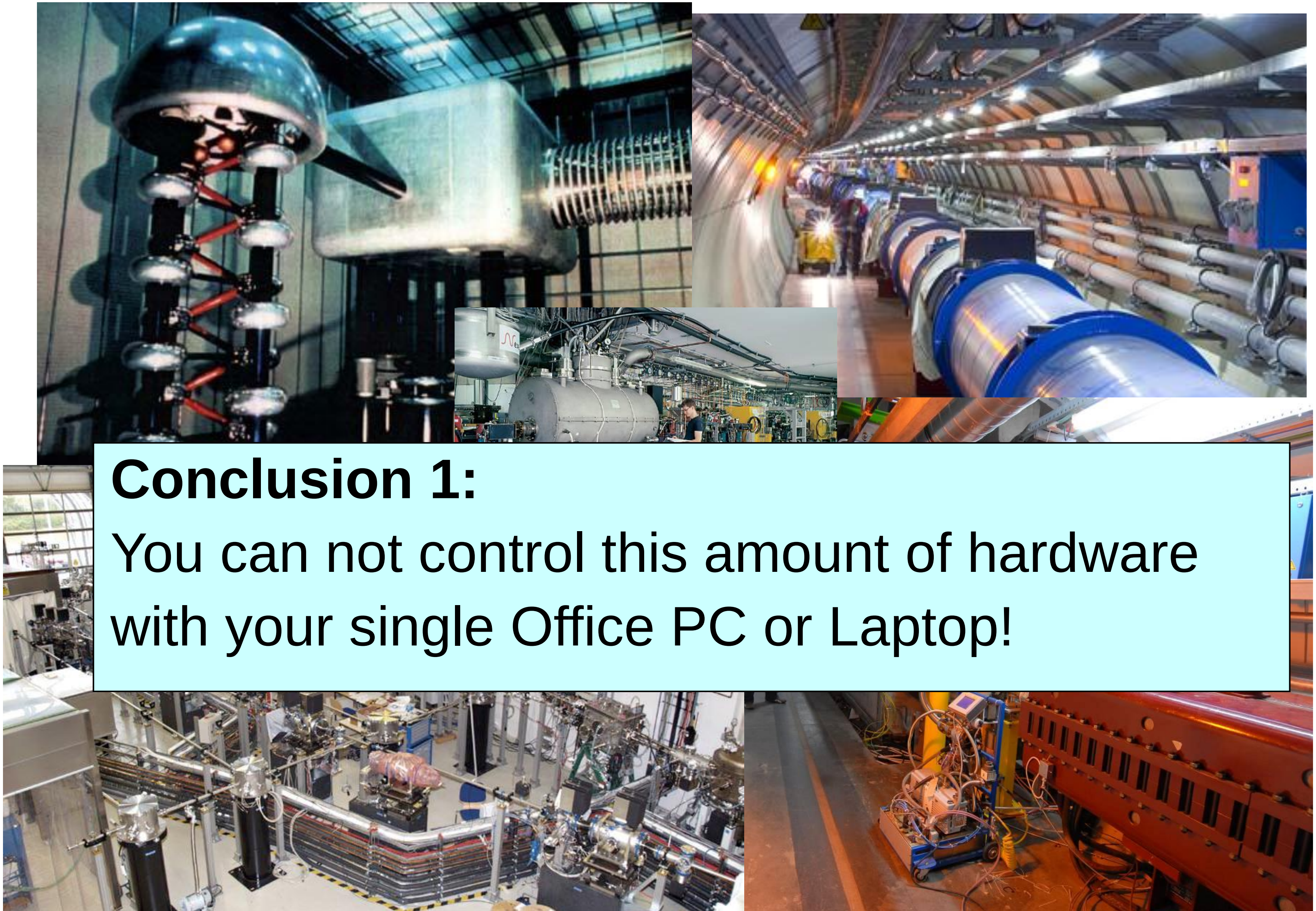
Accelerator Controls

JUAS 2012

JUAS
Joint Universities Accelerator School

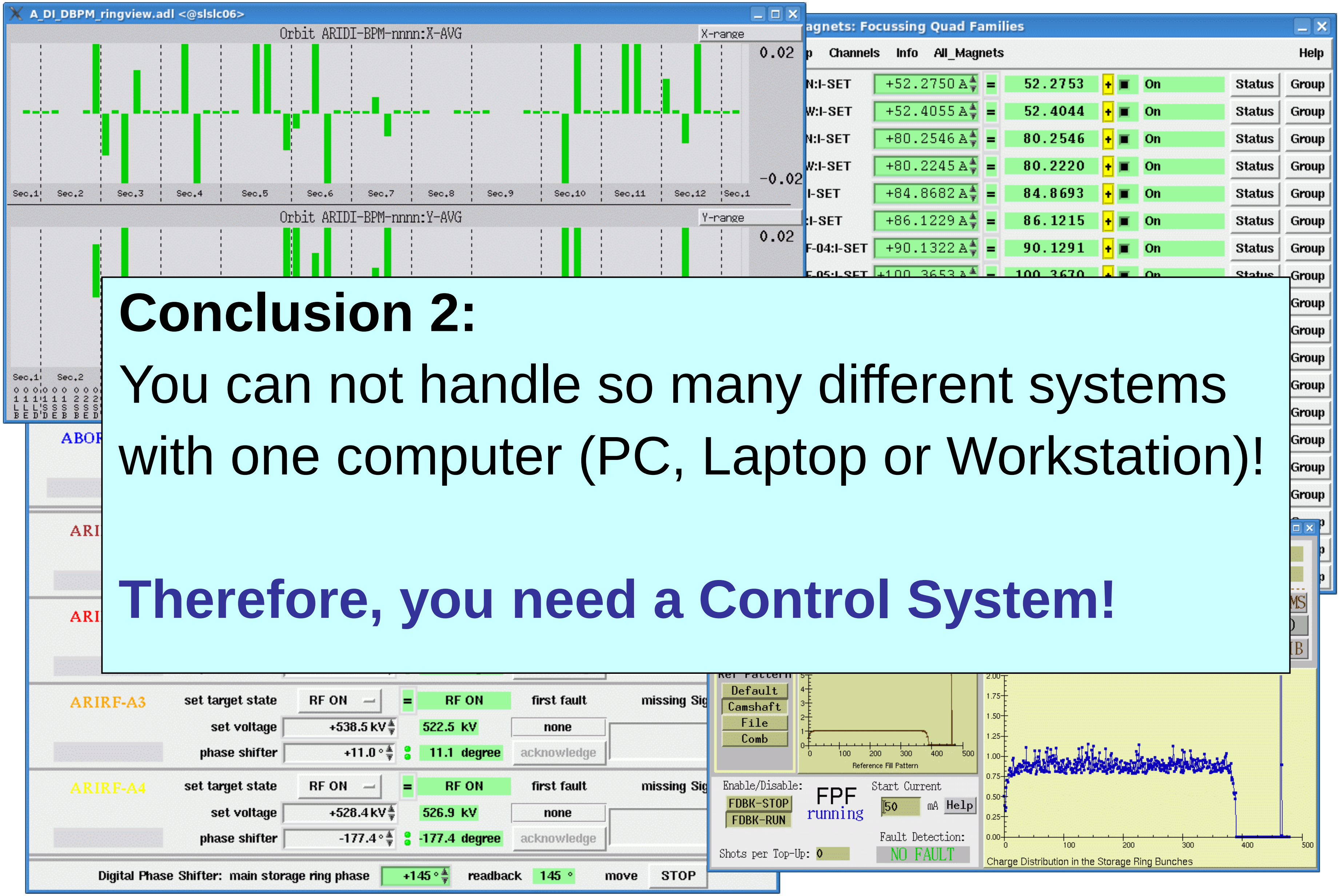
Motivation 1



Conclusion 1:

You can not control this amount of hardware with your single Office PC or Laptop!

Motivation 2



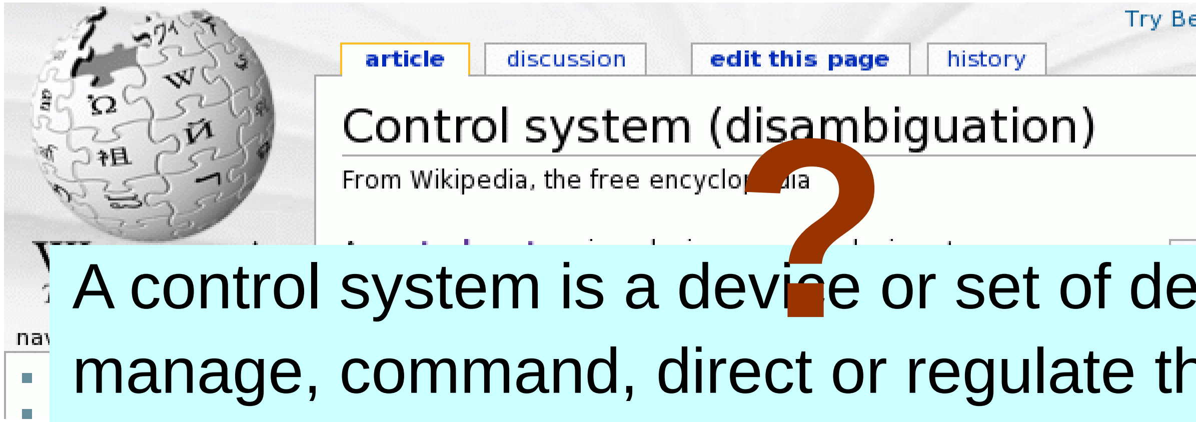
Conclusion 2:

You can not handle so many different systems with one computer (PC, Laptop or Workstation)!

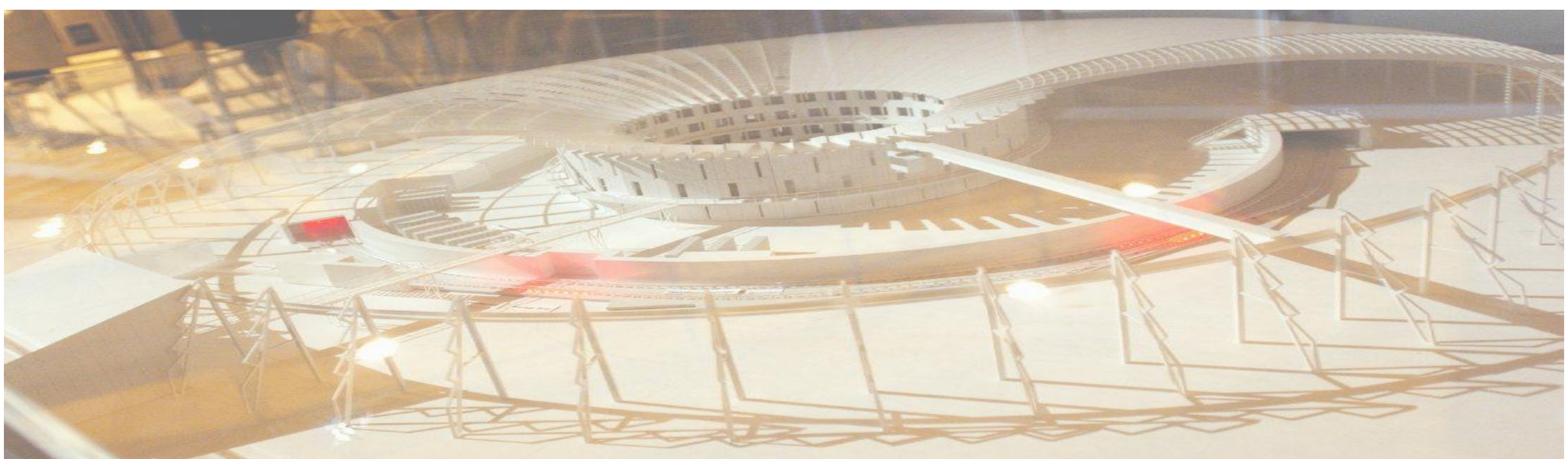
Therefore, you need a Control System!

Table of Content

What is a Accelerato Control System



A control system is a device or set of devices to manage, command, direct or regulate the behavior of other devices or systems.



What ~~is~~ does an Accelerator Controls System

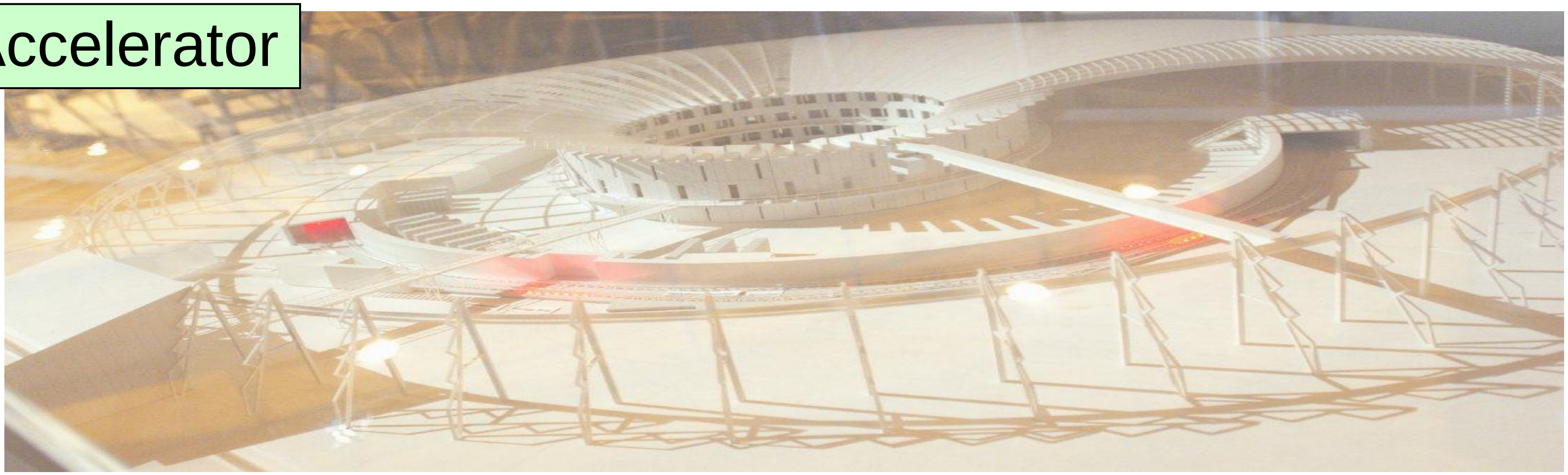
Control System

- Controls the accelerator (Source, Magnets, RF)
- Provides diagnostics information (BPMs, Cameras)
- Monitors environment (Vacuum, Temperature)
- Feedback programs for beam parameters (orbit feedback)
- Makes “the machine” running and controllable …

… reliable, with good performance, flexible … economical

?

Accelerator



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Who uses an Accelerator Controls System

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Who they are

- Accelerator Physicists
- Operators (technical Staff, in most cases no theoretical background knowledge)
- System Experts (Vacuum Experts, RF Group, …)
- Experiment Users (not necessary Physicists)
- Sponsors (Politicians, General Public, etc.)
- Control System Specialists (Computer Scientists, Physicists, Nerds)

What they want from the system

- Access to ALL functions of the hardware (full control)
- Implementation of complex algorithms
- Easy and intuitive usage
- Low cost, low manpower
- Safe usage and reliable alarm handling
- Easy maintainable
- Easy extensible
- **fun**

Requirements for the Accelerator Control System:

At an accelerator facility

- a lot of different user groups
- with different requirements
- have to be satisfied simultaneously

What is the Technical Environment?

Control Systems (one way or another) have to deal with …

- **Distributed** end points and processes
- **Data Acquisition** (front end hardware)
- **Real-time** needs (where necessary)
- **Process control** (automation, feedback, PID controller)
- **Central Services** (Archive, Databases, Name Resolution)
- **Data transport** (control system protocol, network)
- **Security** (who’s allowed to do what from where?)
- **Time synchronization** (time stamps, cycle ids, etc.)

that is:

Computers (in different flavors) and **Computer Environment**

Requirements for the Accelerator Control System:

At an accelerator facility

– a lot of different user groups

– with different requirements

– have to be satisfied simultaneously

\+ **using a computer based environment**

Definition:

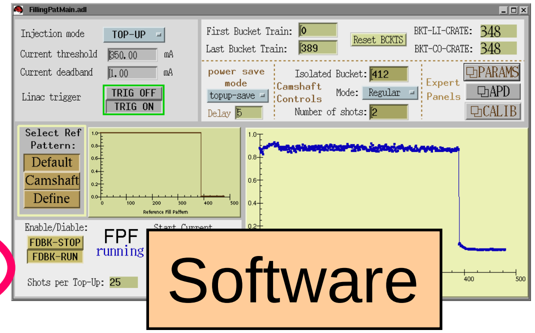
An **Accelerator Control System** is a computer environment to solve simultaneously requirements of different user groups to run an accelerator.

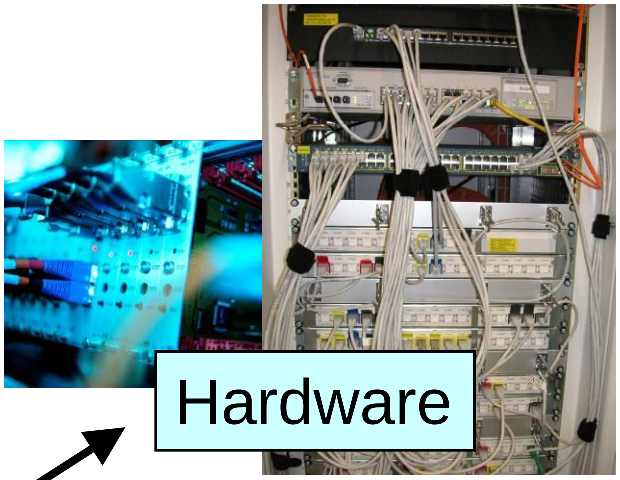
Table of Content

- What is an Accelerator Control System?
- Accelerator Control Systems Architecture
- Examples of Control Systems
- … Coffee Break …
- Control Systems Hardware Examples
- Borderlands of Control Systems
- Conclusion

Goals and Expectations of a Control System

- reliable
- good performance
- flexible
- economical
- easy maintenance?





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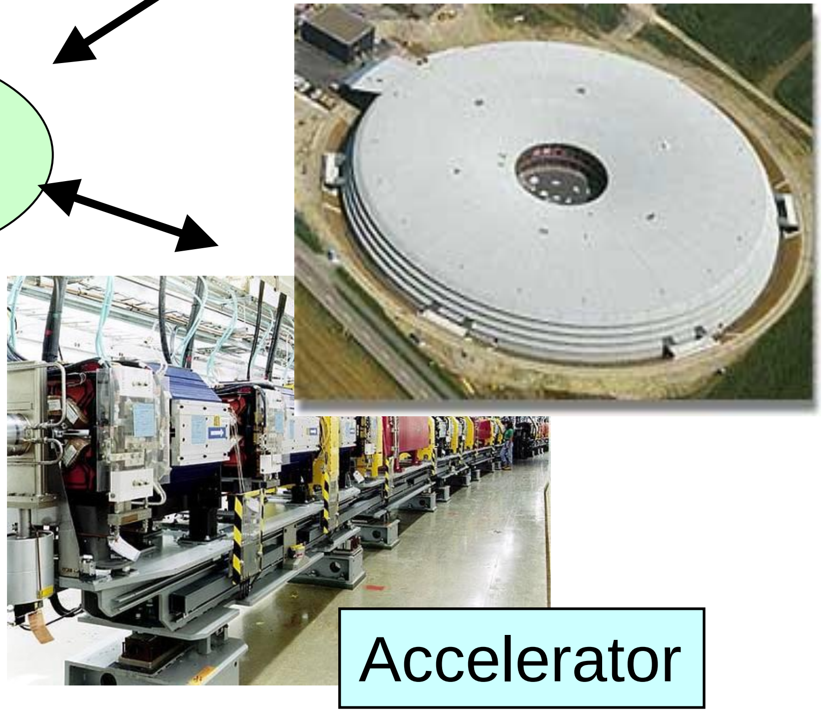
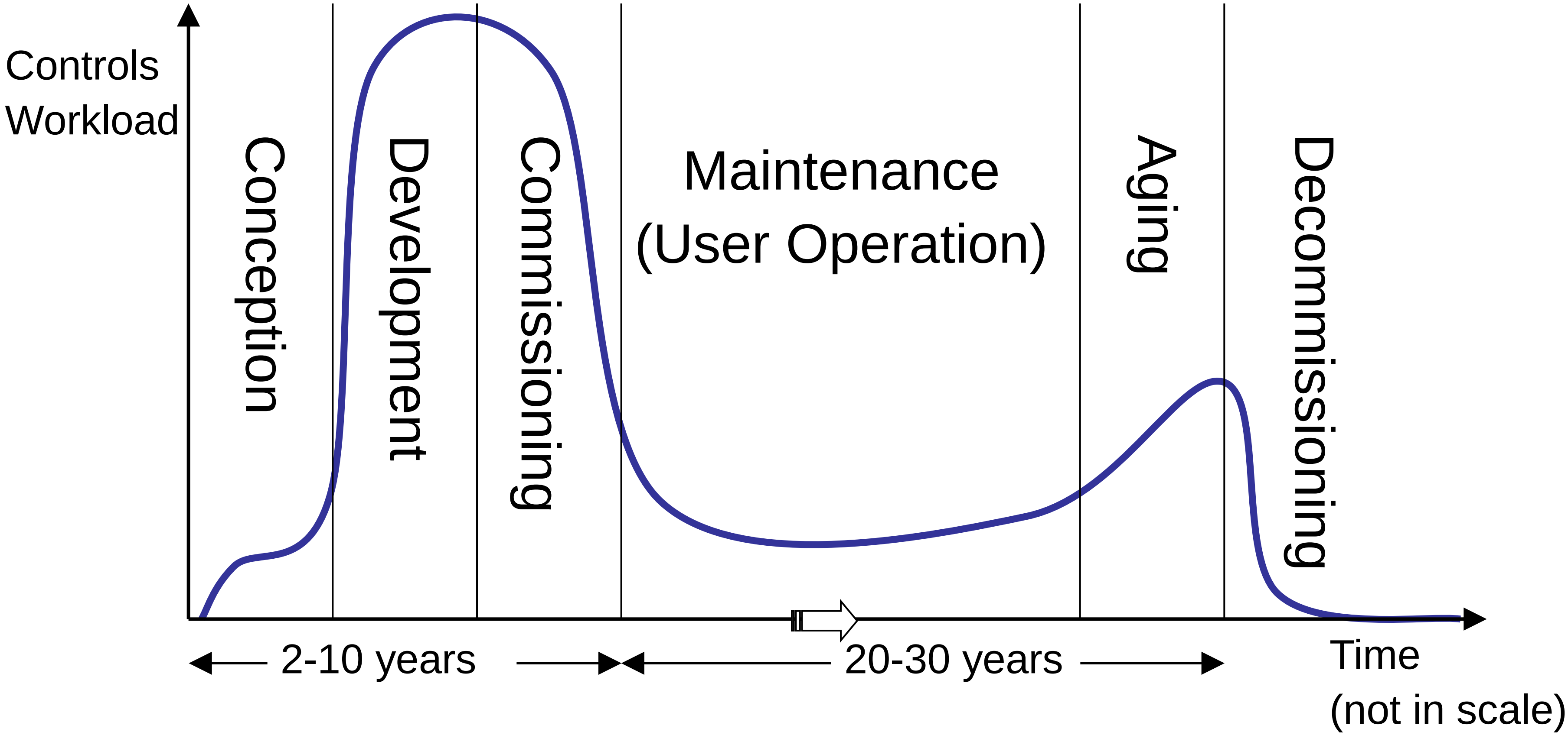


Why is easy Maintenance important?

Controls System Lifecycle:



- "*You have to run to stay where you are*"
- Workload never got to zero during accelerator lifetime
- Normal accelerator lifetime ~ 30 to 40 years

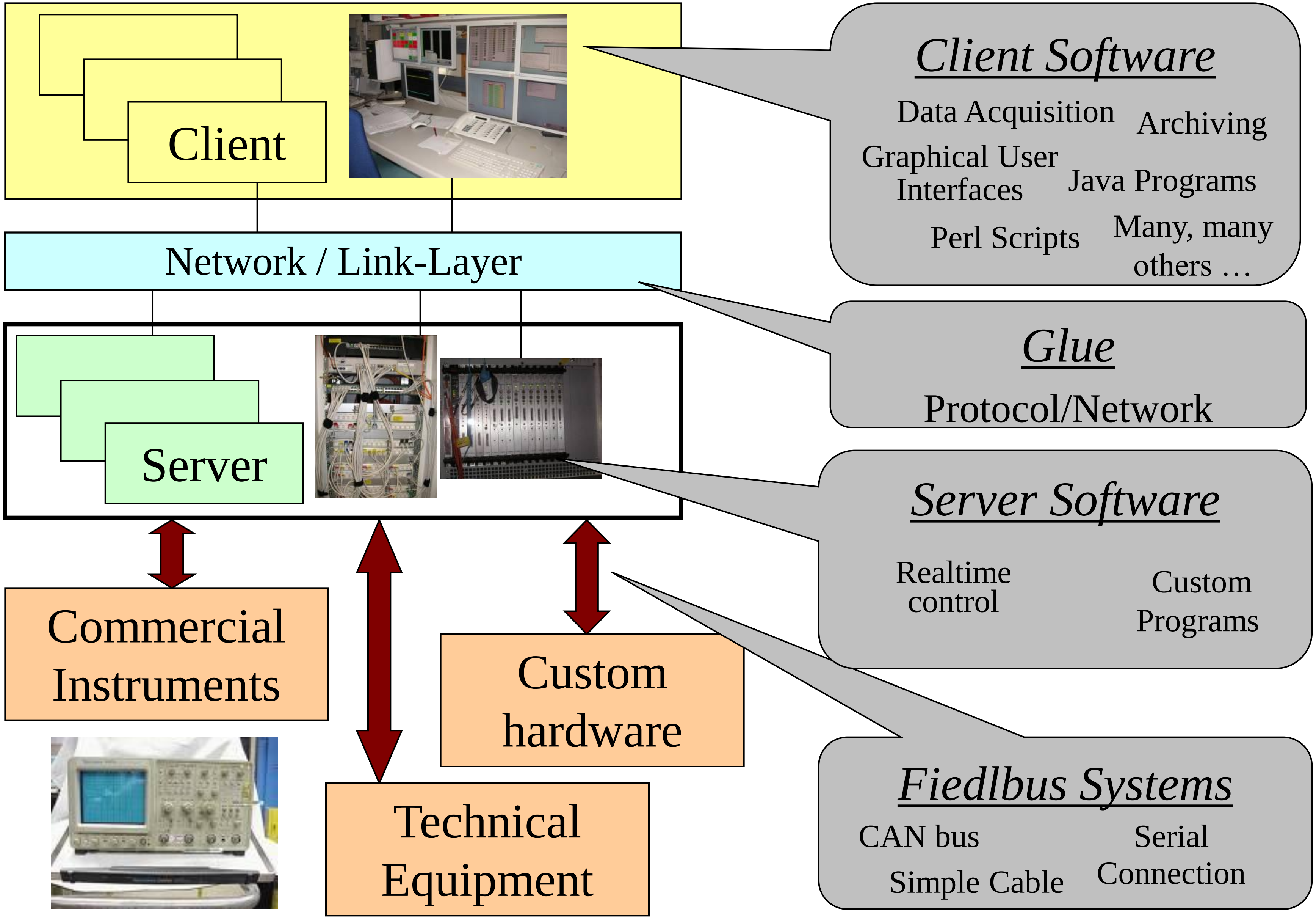
Technical Requirements

As far as reasonable possible:

Why?

- Use open source firmware/software.
  - You can change things and you have control of further developments
- Use commercial solutions based on open standards developed and sold by a large number of companies
  - Don't become dependent on single companies with proprietary solutions
- Use standards with a long life-time (20 years+)
  - Keep long lifecycles of accelerators in mind
- Minimize the number of standards among different facilities at the same institute
  - You have not infinite manpower and time to support different systems

(Standard) Control System Layer Model



Where is Physics in there?

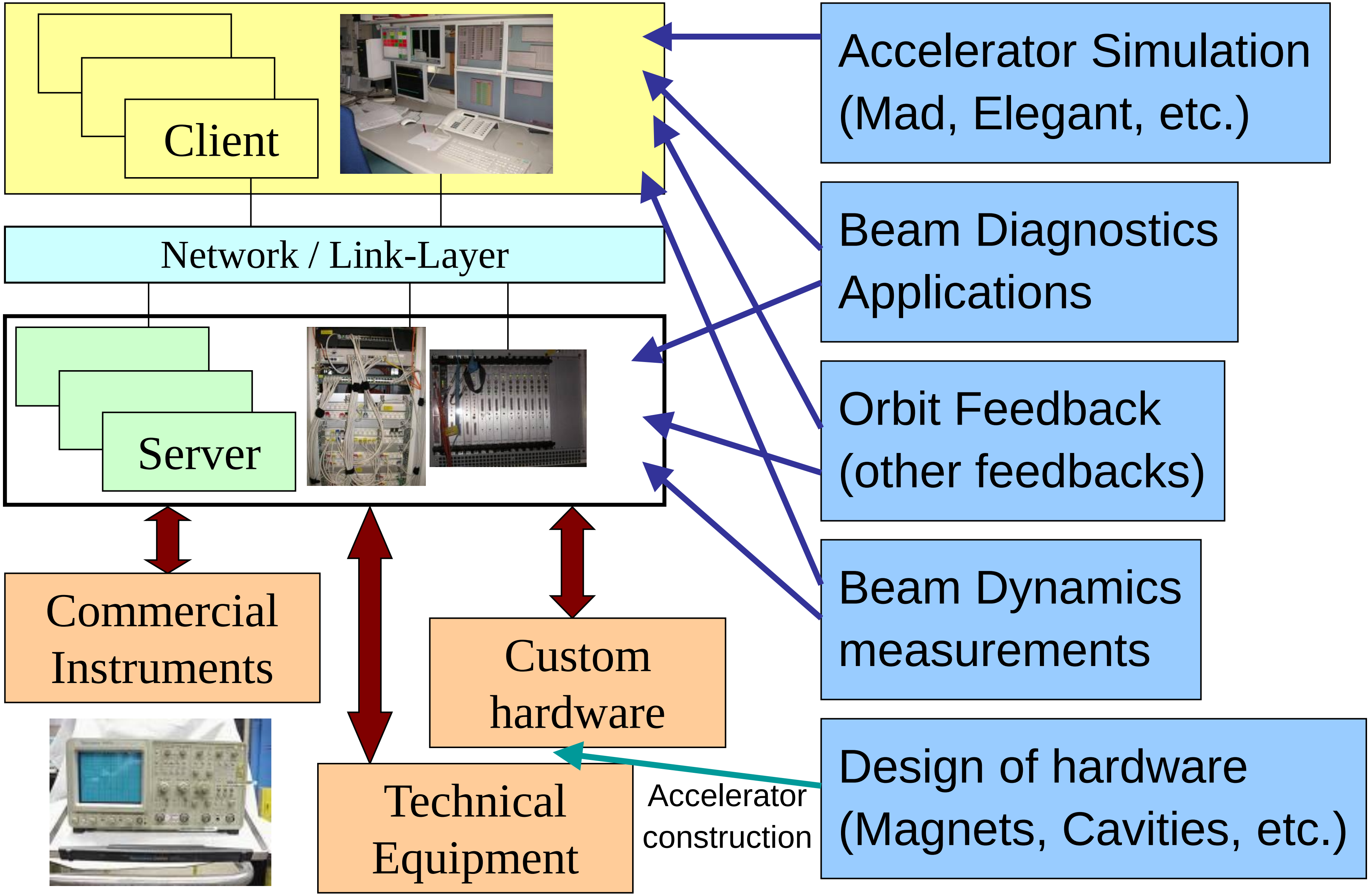


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Table of Content

Solutions: Different Control System Examples

System Name:

- **EPICS**
- **TANGO**

Collaborations:
Used at more than one Lab

Pro:
Bugs are already found

Contra:
Complicated to adapt to your problems

- **DOOCS**
- **ACS**

Single Site Systems:
Developed and used in one Lab

Pro:
Your problems solved perfectly

Contra:
You are on your own (no one can help)

- **SCADA (PVSS)**

Commercial System

Pro:
Outsource your problems

Contra:
Expensive

What is EPICS?

- **EPICS** (**E**xperimental **P**hysics and **I**ndustrial **C**ontrol **S**ystem)
  - is a set of software tools and applications
  - provides a software infrastructure
  - supports distributed control systems for large research facilities like accelerators
  - uses Client/Server and Publish/Subscribe methods
  - uses the Channel Access (CA) network protocol
- In 1989 started a collaboration between Los Alamos National Laboratory (GTA) and Argonne National Laboratory (APS)

  (Jeff Hill, Bob Dalesio & Marty Kraimer)
- More than 150 licenses agreements were signed, before EPICS became Open Source in 2004

GTA: Ground Test Accelerator
APS: Advanced Photon Source

http://www.aps.anl.gov/epics/

Who uses EPICS (Very Incomplete List)?

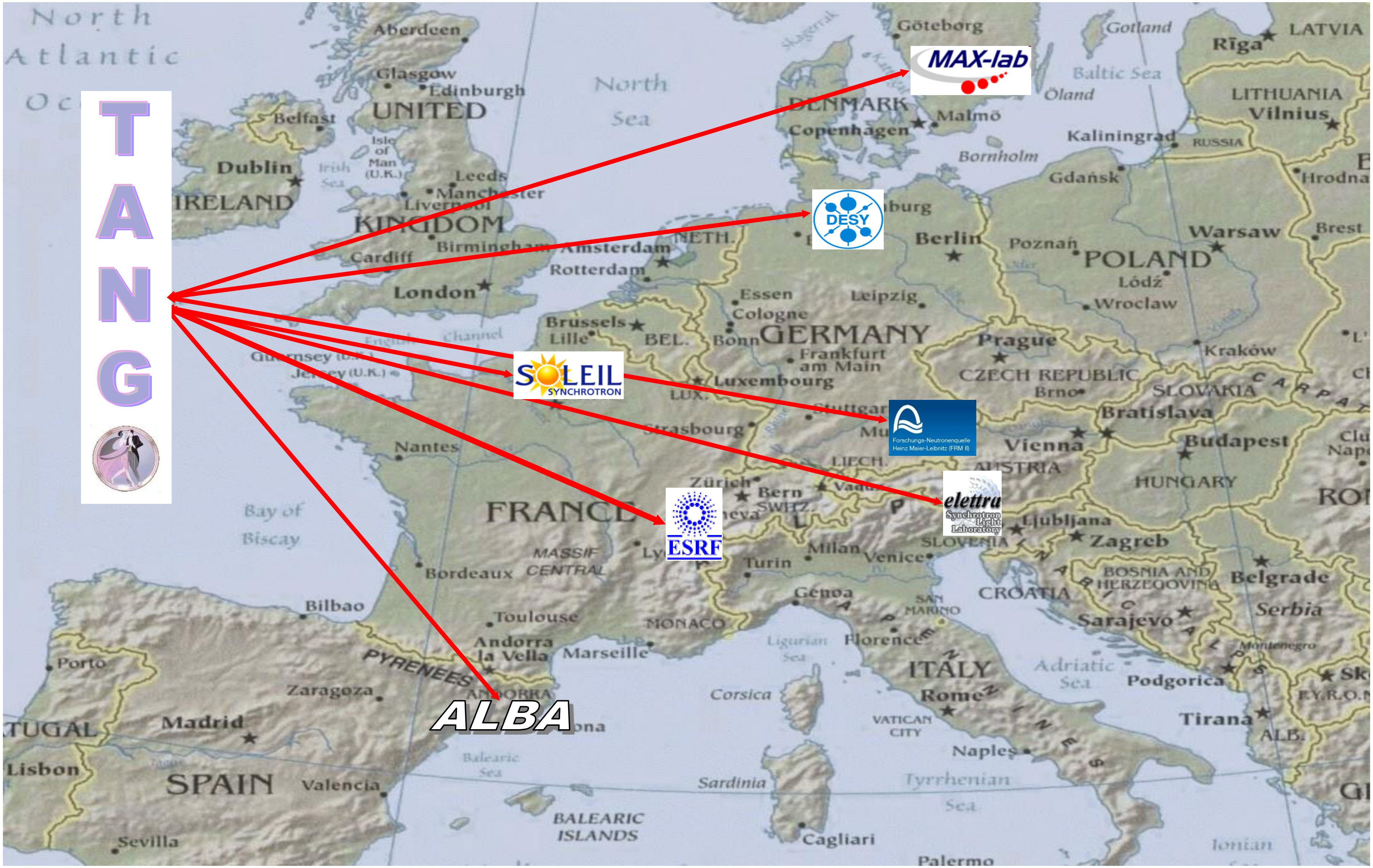
What is Tango?

- **TANGO** (**TA**co **N**ext **G**eneration **O**bjects)
  - is a strictly object oriented toolbox for Control System development
  - is a set of software tools and applications
  - supports distributed control systems for accelerators
  - is using CORBA as the protocol layer
  - is a special adaptation of CORBA
  - hides the complexity of Corba to the programmer
  - adds specific control system features
- Started in 2001 with three collaborators, now there are seven

CORBA =
Common Object Request Broker Architecture

http://www.tango-controls.org/

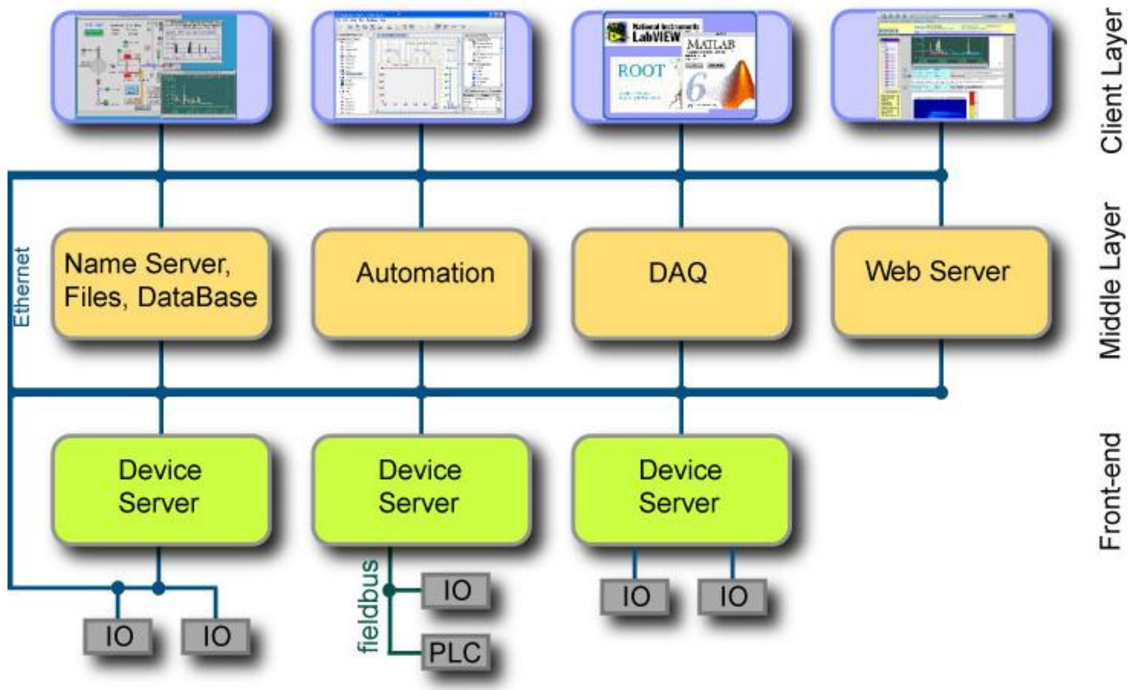
Who is using Tango?



What is DOOCS (at DESY)?

DOOCS (**D**istributed **O**bject **O**riented **C**ontrol **S**ystem)

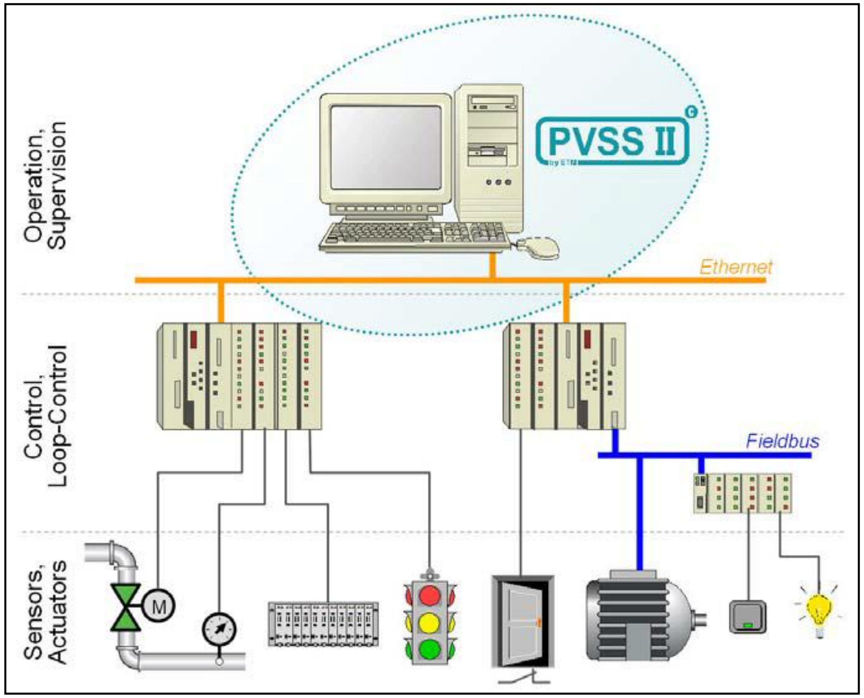
- strictly object oriented system design (C++ and Java)
- Class libraries as building blocks



- Build for FLASH, now used as well for European XFEL

http://tesla.desy.de/doocs/index.html

What is PVSS (at CERN)?



PVSS II (**P**rozess**v**isualisierungs- und **S**teuerungs**s**ystem 2)

- is an industrial SCADA product from the Austrian company ETM (bought by Siemens AG in 2007)

SCADA = **S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition
(commercial software systems used extensively in industry for the supervision and control of industrial processes)

http://www.etm.at/
http://j2eeps.cern.ch/wikis/display/EN/PVSS+Service/

Mixed Systems

- At DESY:
  Tango, EPICS, and DOOCS mixed
- At PSI:
  ACS – EPICS migration
- At PSI (former SLS beamline):
  Tango beamline at EPICS accelerator


By Evan Swigart

- There are gateways between the systems
  - For example: Epics2TINE and Tango2TINE

The choice for one system is not exclusive

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Table of Content

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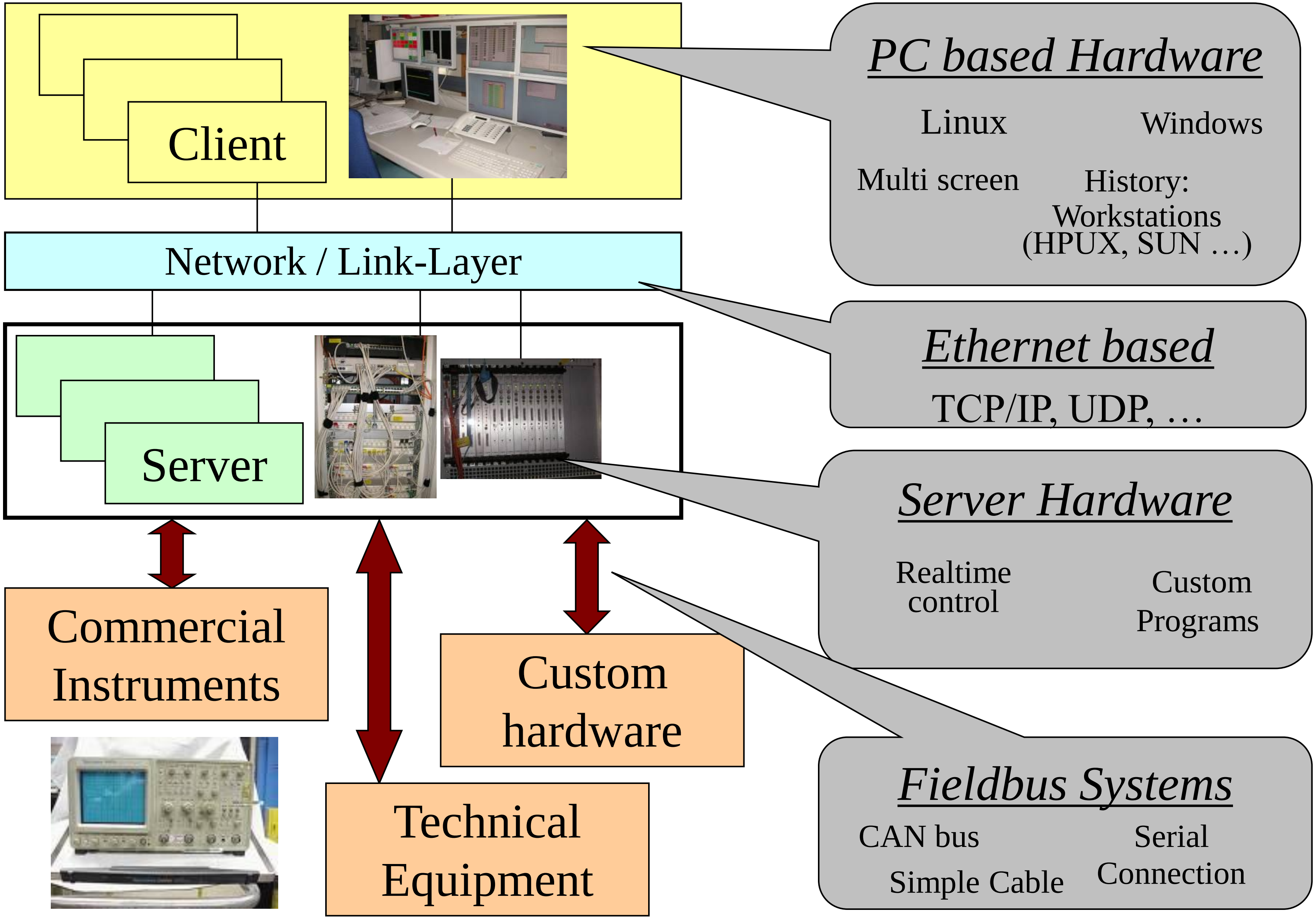
- What is an Accelerator Control System?
- Accelerator Control Systems Architecture
- Examples of Control Systems

!!! Coffee break !!!

- Control Systems Hardware Examples
- Borderlands of Control Systems
- Conclusion

Table of Content

Reminder: (Standard) Control System Layer Model



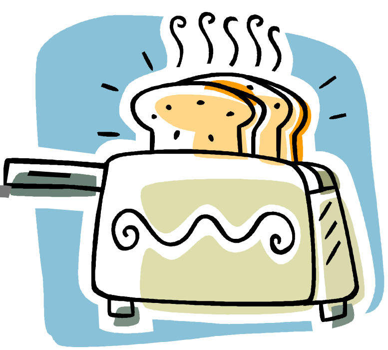
The Cheap Solution: PC based

user interface

Ethernet

Server Hardware

Custom Hardware



field bus (ethernet, serial, USB, firewire, …)

PCs are cheap, have standard network interfaces and support other field busses

PCs life cycles are short compared to accelerators (no spares available after some time)

The Classic Solution: VME based

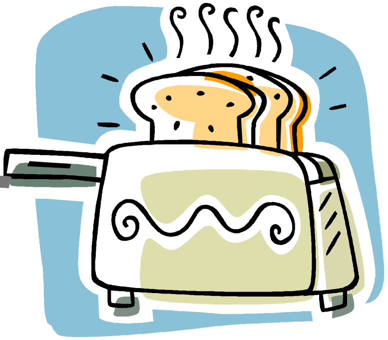
user interface

Server Hardware

VME (Operating System: e.g. vxWorks)

Ethernet

Dumb Hardware



Cable or field bus (analog I/O, digital I/O,…)

VME cards life cycle is long,
VMEbus is an open standard,
Supported by Industry

VME is expensive,
special operating system
(VxWorks)

What is a VME Computer?

- VME is an abbreviation for **V**ERSA**m**odule **E**urocard
- Industry Computer based on VMEbus
- Developed since 1980
- It is not a PC
- Real-time capable (i.e. delays are calculable)
- Common used operating system is VxWorks from Wind River company (open source alternative: RTEMS)
- Expensive (~800 Euro per interface card)

VME Crate

VME Card:
Eurocard size
VMEbus interface

http://en.wikipedia.org/wiki/VMEbus

A serial interface solution: Picotux based

user interface

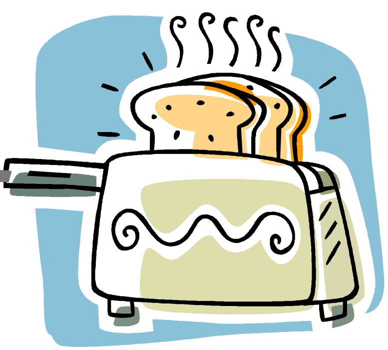
Ethernet

Server Hardware

Linux PC

Example for tiny computers with single interface

Hardware with serial interface



Serial interface (RS232, …)

Cheap and tiny solution,

Supports distributed devices

All commercial chips have slightly different architecture (maitenance), life cycle yet unknown

The Embedded Solution: Device Integrated CPU

user interface

Embedded Hardware

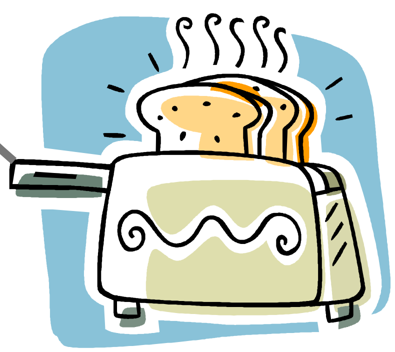
=

Server Hardware

+

Instrument

Ethernet



Low cost, have standard network interfaces and support distributed devices

All commercial chips have slightly different architecture (maitenance), life cycle yet unknown

What are PLCs?

- **PLC** (**P**rogrammable **L**ogic **C**ontroller)
  - is a digital computer used to connect “dumb” devices
- the PLC is designed
  - for multiple inputs and output arrangements
  - extended temperature ranges
  - immunity to electrical noise
  - resistance to vibration and impact
  - as a real time system

- Programs are typically stored in battery-backed or non-volatile memory
- Products from different providers can **NOT** be mixed!
- Examples for companies:
  - Siemens S7 (http://www.automation.siemens.com/mcms/programmable-logic-controller/en/Pages/Default.aspx)
  - Allen-Bradley http://www.ab.com/programmablecontrol/plc/

Field Busses

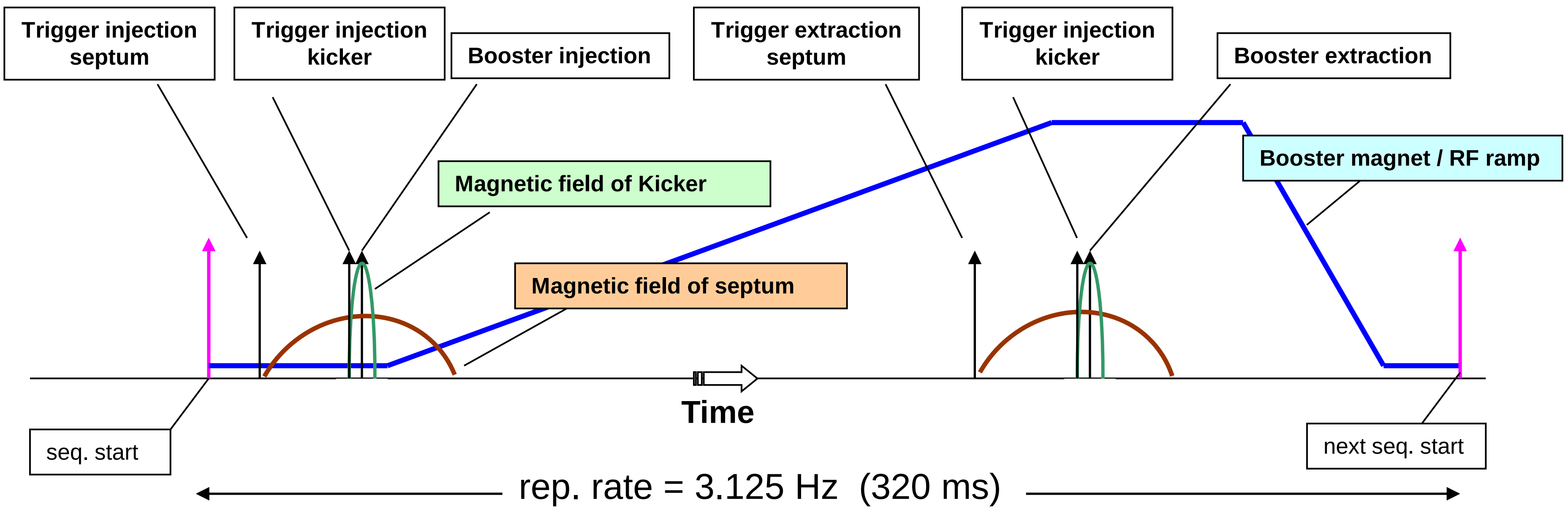
- Field busses connect hardware to servers
- A lot different busses available with different purposes (number of allowed devices and speed can differ a lot)
- Some example field bus systems:
  - **CANbus** (Controller area network)
    http://en.wikipedia.org/wiki/Controller_area_network
  - **GPIB**/IEEE-488 (General Purpose Interface Bus)
    http://en.wikipedia.org/wiki/IEEE-488
  - **PROFIBUS** (Process Field Bus)
    http://en.wikipedia.org/wiki/Profibus
  - **IEEE 1394** (Firewire)
    http://en.wikipedia.org/wiki/IEEE_1394_interface
- Difference to Ethernet and USB?
  Field busses are real time capable (IEC 61158 specification)
- But **Ethernet** and **USB** are used in place of field busses

Table of Content

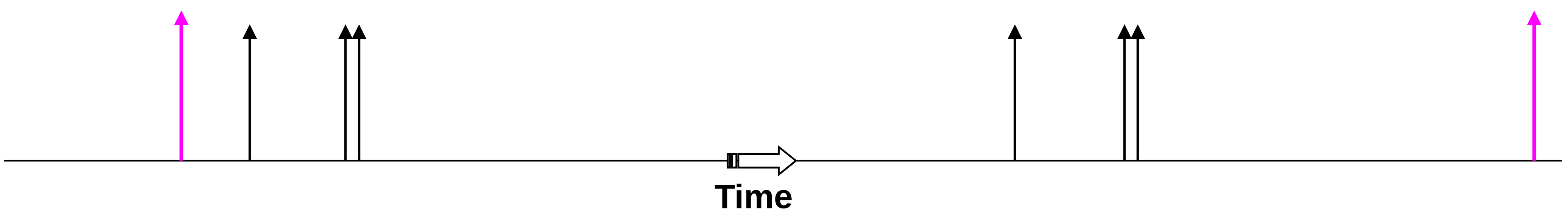
Borderlands of Control Systems

- Timing and Synchronisation
- Interlock-, Alarm-, and Machine Protection Systems
- Experiment Data Acquisition
- Relational Databases
- Relationship of IT (Information Technology) and Controls

Why Synchronize?



Event sequence for booster synchronization:



Solutions for Timing Systems

- Master oscillator + delay cables
  (1 trigger and measured cable lengths)

- Master oscillator + digital delay generators
  (http://www.thinksrs.com/products/DG535.htm)

- (Master oscillator +) event generators/receiver cards in computers (PC or VME)
  (http://www.mrf.fi/)

- Timing and synchronization is needed to run an accelerator
- Various solutions available and used

Timing and synchronization can be part of the Control System. Clarify who is responsible for timing and synchronization to avoid problems!

Borderlands of Control Systems

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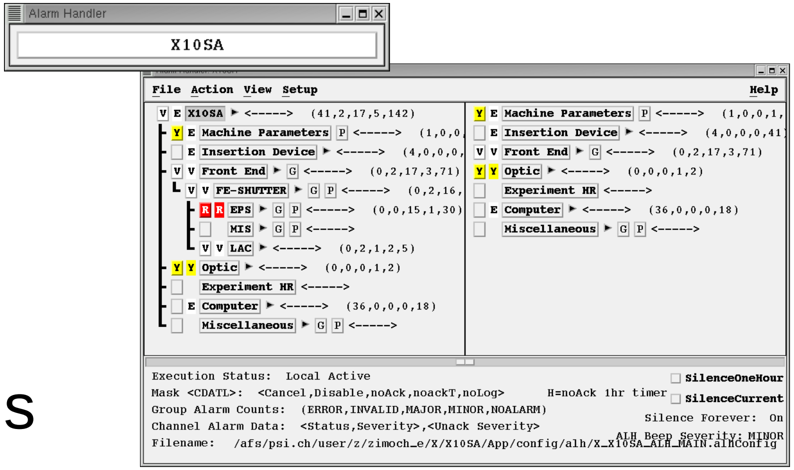
What are Alarms



EPICS Alarmhandler

Murphy's law:

Anything that can go wrong will go wrong.

- Alarms help to avoid Real Problems
- Alarms help to find problems
- Example:
  - Beam position more than 1 mm of from reference
  - Vacuum pressure higher than 1e-6 mbar
  - Orbit Feedback Program not running

- People should react on alarms

What are Interlocks?

Everything is fine (No Alarm)

Example: Vacuum pressure 1e-10 mbar

Go on working

Something is strange (Warning)

Example: Vacuum pressure 1e-7 mbar

Something is wrong (Error)

Example: Vacuum pressure 1e-6 mbar

Alarm states

Alert people to take some actions

Stop it or suffer from severe consequences (Interlock)

Example: Vacuum pressure 1e-5 mbar
Automatic beam dump executed

Interlock

Automatic reaction needed

Interlock Systems

- Interlock Systems have to be
  - taking automatic actions (no people involved)
  - Reliable (99% might not be enough)
  - as simple as possible (see Murphy's law)
  - fast
- Avoid computers in Interlock Systems (at least choose reliable ones or redundant systems)
- Decouple "running" the accelerator (=Control System) from "stopping" the accelerator (=Interlock System)
- There can/will be more than one Interlock System in an accelerator (local, global, different goals, etc.), for example:
  - Vacuum Interlock
  - Equipment Protection System
  - local RF Interlock Systems

Clarify who is responsible for Interlock Systems to avoid problems!

Borderlands of Control Systems

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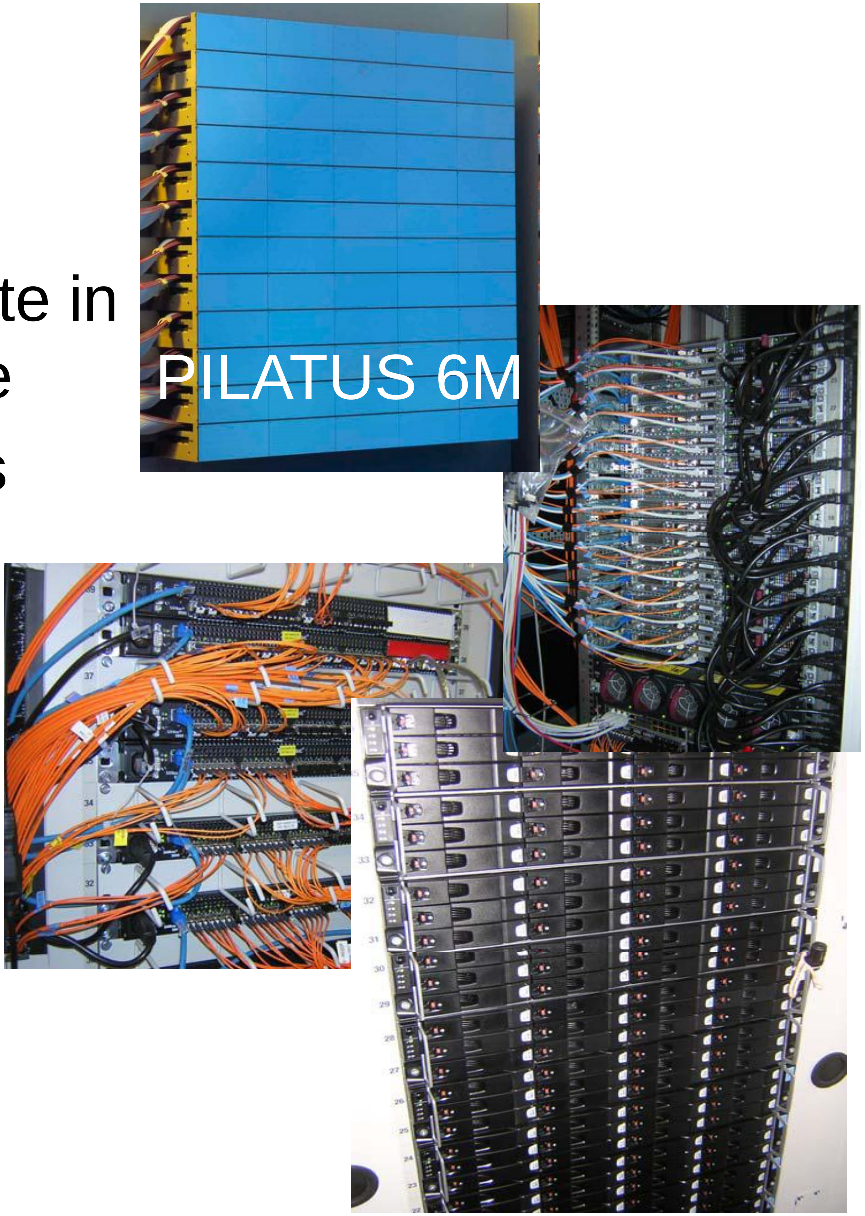
Data Acquisition (Examples)

- **PILATUS 6M Detector** (Synchrotron-Beamline at SLS):
  - two-dimensional hybrid pixel array detectors, which operate in single-photon counting mode
  - composed of 5 x 12 modules with 2463 x 2527 pixels
  - Framing rate12 Hz for ca. 6 MByte = 72 MB/s
  - at full speed: 8 hours ≈ 1.6 TeraByte

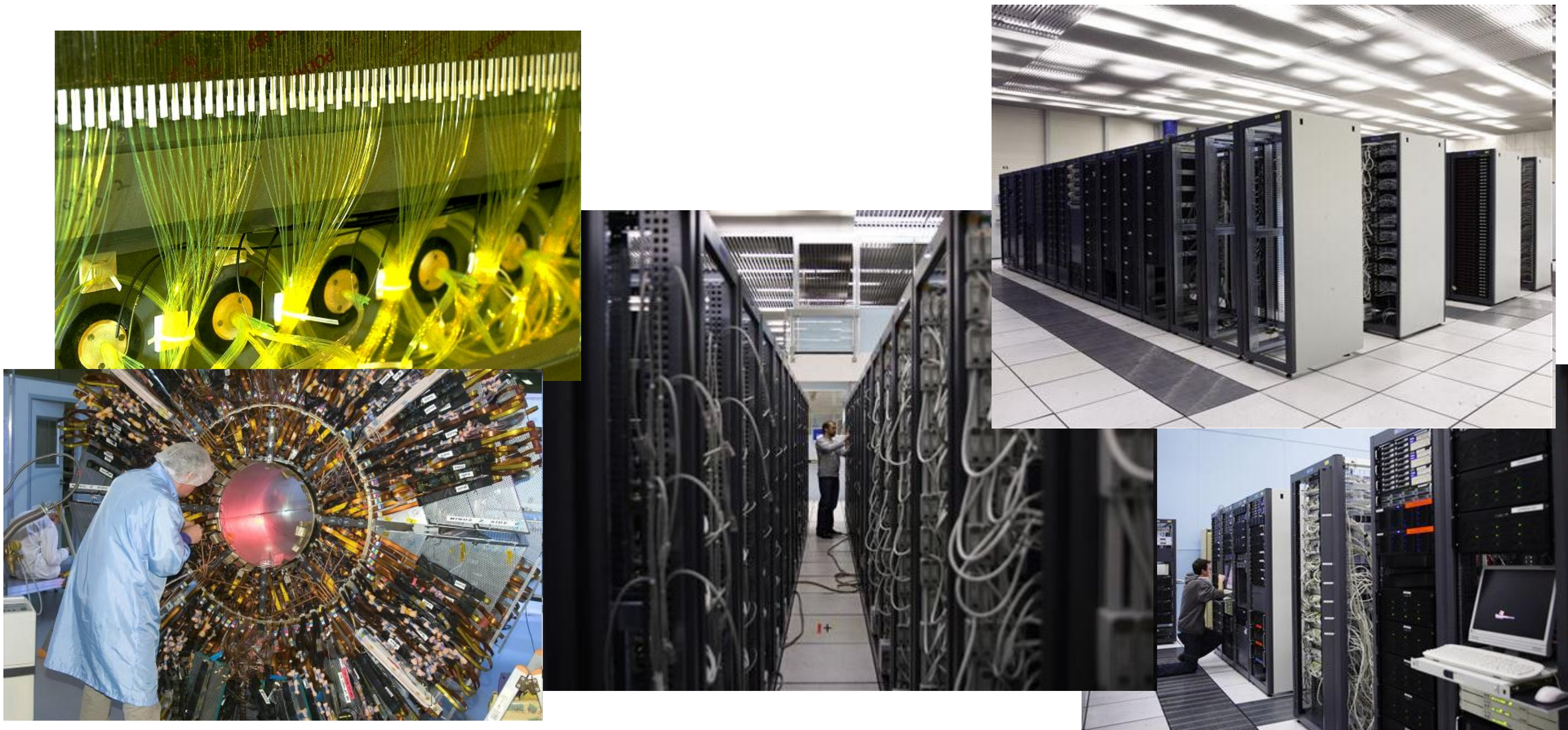


http://pilatus.web.psi.ch/index.htm

http://www.dectris.com/

Data Acquisition (Examples)

- The Large Hadron Collider will produce roughly 15 petabytes (15 million gigabytes) of data annually – enough to fill more than 1.7 million dual-layer DVDs a year!
  - GRID computing to allow access http://www.gridcafe.org/



Is Data Acquisition Controls?

- Data Acquisition requires
  - Network infrastructure
  - Computer storage infrastructure
  - Server infrastructure for data access
  - Environment (e.g. Grid) for data access
  - Manpower for setup and maintenance
- Detectors
  - can provide useful information about accelerator (beam position)
  - need to be adjusted to accelerator setup (connection to control system needed)
- Some detectors (e.g. BPMs) are part of the accelerator anyway

Not necessary

Yes its needed

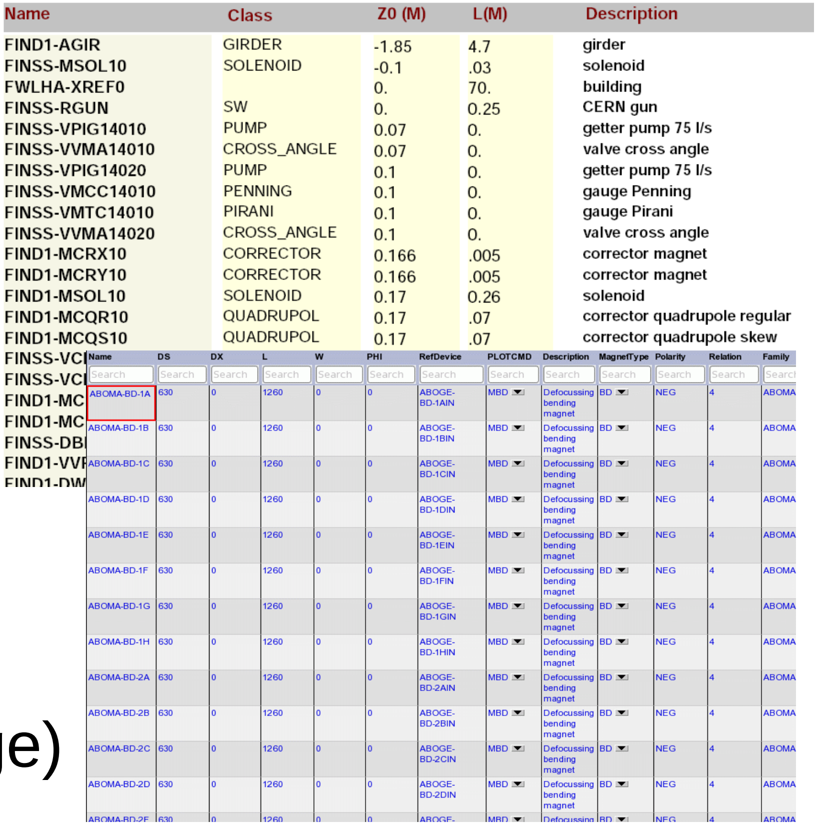
Has to be discussed to avoid problems!

Borderlands of Control Systems

- Timing and Synchronisation
- Interlock-, Alarm-, and Machine Protection Systems
- Experiment Data Acquisition
- Relational Databases
- Relationship of IT (Information Technology) and Controls

What is a Relational Database?

- Used for "stable" Data (Lattice, Magnet Data etc.)
- Good for searching
- Might be slow for runtime data
- Examples:
  - Oracle
  - MySQL
  - MSAccess
- Language to access data is SQL (Structured Query Language) for all examples



Name	Class	Z0 (M)	L(M)	Description
FIND1-AGIR	GIRDER	-1.85	4.7	girder
FINSS-MSOL10	SOLENOID	-0.1	.03	solenoid
FWLHA-XREF0		0.	70.	building
FINSS-RGUN	SW	0.	0.25	CERN gun
FINSS-VPIG14010	PUMP	0.07	0.	getter pump 75 l/s
FINSS-VVMA14010	CROSS_ANGLE	0.07	0.	valve cross angle
FINSS-VPIG14020	PUMP	0.1	0.	getter pump 75 l/s
FINSS-VMCC14010	PENNING	0.1	0.	gauge Penning
FINSS-VMTC14010	PIRANI	0.1	0.	gauge Pirani
FINSS-VVMA14020	CROSS_ANGLE	0.1	0.	valve cross angle
FIND1-MCRX10	CORRECTOR	0.166	.005	corrector magnet
FIND1-MCRY10	CORRECTOR	0.166	.005	corrector magnet
FIND1-MSOL10	SOLENOID	0.17	0.26	solenoid
FIND1-MCQR10	QUADRUPOL	0.17	.07	corrector quadrupole regular
FIND1-MCQS10	QUADRUPOL	0.17	.07	corrector quadrupole skew
FINSS-VCI				
FINSS-VCI				
FIND1-MC				
FIND1-MC				
FINSS-DBI				
FIND1-VVI				
FIND1-DW				

Name	DS	DX	L	W	PHI	RefDevice	PLOTCMD	Description	MagnetType	Polarity	Relation	Family
Search	Search	Search	Search	Search	Search	Search	Search	Search	Search	Search	Search	Searc
ABOMA-BD-1A	630	0	1260	0	0	ABOGE-BD-1AIN	MBD	Defocussing bending magnet	BD	NEG	4	ABOMA
ABOMA-BD-1B	630	0	1260	0	0	ABOGE-BD-1BIN	MBD	Defocussing bending magnet	BD	NEG	4	ABOMA
ABOMA-BD-1C	630	0	1260	0	0	ABOGE-BD-1CIN	MBD	Defocussing bending magnet	BD	NEG	4	ABOMA
ABOMA-BD-1D	630	0	1260	0	0	ABOGE-BD-1DIN	MBD	Defocussing bending magnet	BD	NEG	4	ABOMA
ABOMA-BD-1E	630	0	1260	0	0	ABOGE-BD-1EIN	MBD	Defocussing bending magnet	BD	NEG	4	ABOMA
ABOMA-BD-1F	630	0	1260	0	0	ABOGE-BD-1FIN	MBD	Defocussing bending magnet	BD	NEG	4	ABOMA
ABOMA-BD-1G	630	0	1260	0	0	ABOGE-BD-1GIN	MBD	Defocussing bending magnet	BD	NEG	4	ABOMA
ABOMA-BD-1H	630	0	1260	0	0	ABOGE-BD-1HIN	MBD	Defocussing bending magnet	BD	NEG	4	ABOMA
ABOMA-BD-2A	630	0	1260	0	0	ABOGE-BD-2AIN	MBD	Defocussing bending magnet	BD	NEG	4	ABOMA
ABOMA-BD-2B	630	0	1260	0	0	ABOGE-BD-2BIN	MBD	Defocussing bending magnet	BD	NEG	4	ABOMA
ABOMA-BD-2C	630	0	1260	0	0	ABOGE-BD-2CIN	MBD	Defocussing bending magnet	BD	NEG	4	ABOMA
ABOMA-BD-2D	630	0	1260	0	0	ABOGE-BD-2DIN	MBD	Defocussing bending magnet	BD	NEG	4	ABOMA
ABOMA-BD-2E	630	0	1260	0	0	ABOGE-	MBD	Defocussing	BD	NEG	4	ABOMA

- Relational Databases are useful for Control Systems
- Some accelerator control systems have integrated relational databases
- Setup and Maintenance require knowledge and manpower

Borderlands of Control Systems

- Timing and Synchronisation
- Interlock-, Alarm-, and Machine Protection Systems
- Experiment Data Acquisition
- Relational Databases
- Relationship of IT (Information Technology) and Controls

Who is Responsible for What?

- Most large research institutes have a Controls Group in addition to a IT Group
- Why separate IT from Controls?

IT	Controls
• Office PC installation • Operating Systems for Office applications • Infrastructure (network cables) • Central Services (Computing Cluster, Server Room …)	• Accelerator computer installation • Integration of accelerator hardware • Control Room applications • Distributed processes

Databases, Timeserver, Network, Security

Controls is dependent on IT.
Responsibilities have to be discussed to avoid problems!

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Table of Content

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Summary: What is Accelerator Controls

- It is hard to define
- It is organized in layers separating hardware from applications
- It is (has to be) a distributed system, involving some network protocols
- The borders are not clearly defined
  - For example: Where starts the hardware responsibility (PLCs, embedded systems)?
- It is not considered science but needs a lot knowledge about science (physics and computer science, sometimes politics)

An **Accelerator Control System** is a computer environment to solve simultaneously requirements of different user groups to run an accelerator.

References

Bad news: There is no book on Accelerator Control Systems

Good news: You can find some things in the Internet

- ICFA Newsletter Number 47 (December 2008) on Control System: http://icfa-usa.jlab.org/archive/newsletter/icfa_bd_nl_47.pdf

- EPICS: http://www.aps.anl.gov/epics/
- Tango: http://www.tango-controls.org/
- CERN Controls Group: https://controls.web.cern.ch/Controls/
- PSI Controls Group: https://controls.web.psi.ch/cgi-bin/twiki/view/Main

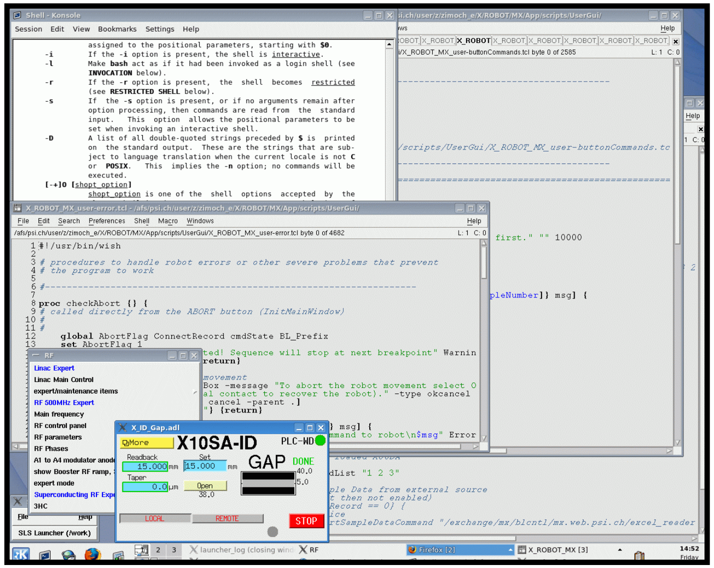
…search the institute web pages …

- International Conference on Accelerator and Large Experimental Physics Control Systems (ICALEPCS): http://www.icalepcs.org/

What to Learn as a Controls Guy?

1. Be curious about what your customers do (accelerator physics, experiments, medical treatment, etc.)
2. Enjoy programming
   – Script Language (phython, tcl/tk, etc.)
   – Object Oriented (Java, C++, etc.)
3. Enjoy computer environments

Quick test:
Do you feel comfortable with this screenshot?



- Useful skills include (non-essential)
  – Basic knowledge in Accelerator Physics or general Physics
  – Database structures/sql commands
  – Linux and/or Windows administration
  – Network administration
  – PLC, FPGA or DSP programming (nearly electronics)
  – Graphical User Interface design