The ILC Control System

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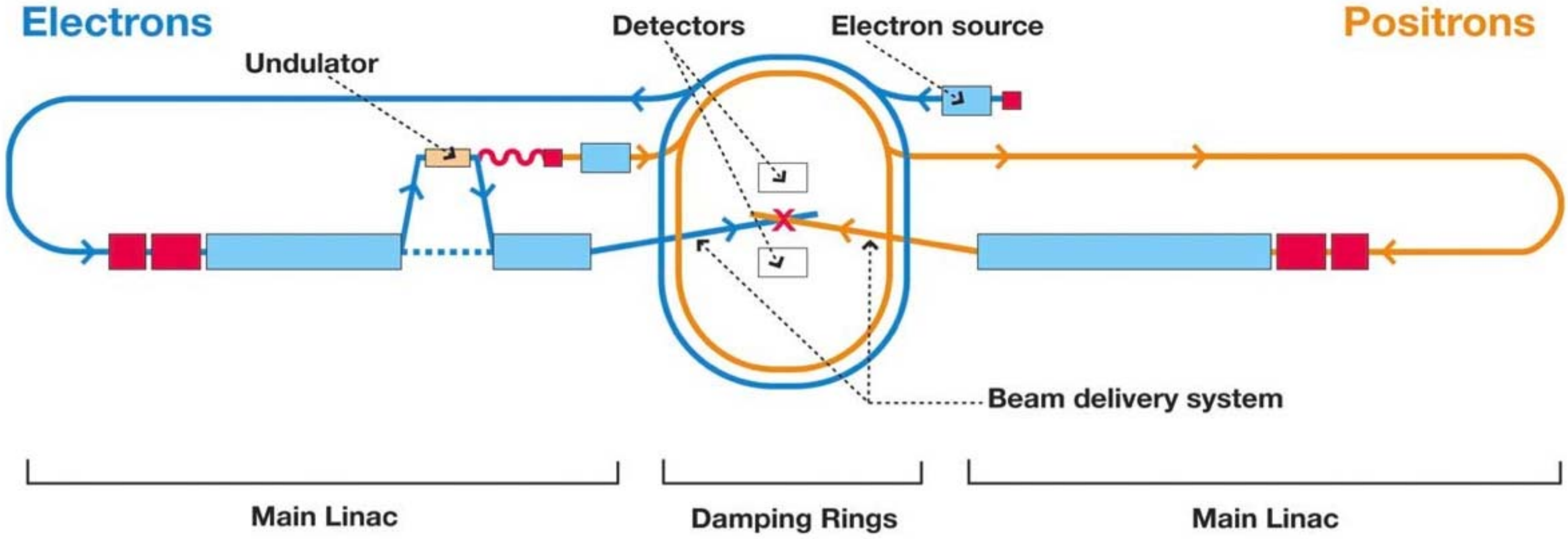
Content

- *ILC overview*
- *Controls challenges and conceptual design*
  - **Availability**
  - **Services**
  - **Configuration management**
- *Collaboration*
- *Wrap-up*

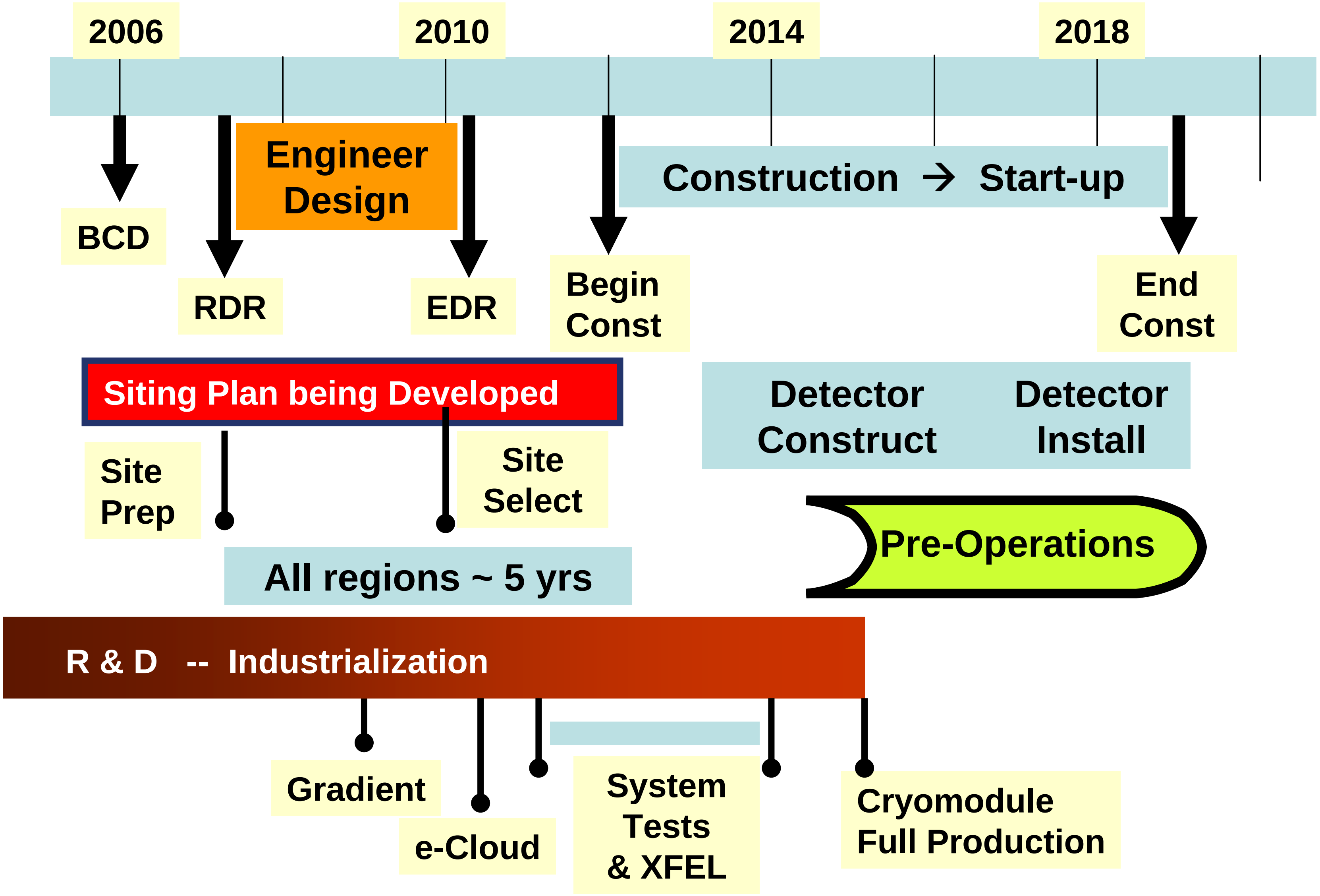
ILC accelerator overview

- Two 11km long 250-GeV linacs with 16,000 cavities and 640 RF units.
- A 4.5-km beam delivery system with a single interaction point.
- 5-GeV electron and positron damping rings, 6.7km circumference.
- Polarized PC gun electron source and undulator-based positron source.



J. Bagger

Technically Driven Timeline



2006

2010

2014

2018

BCD

RDR

Engineer Design

EDR

Begin Const

Construction → Start-up

End Const

Siting Plan being Developed

Site Prep

Site Select

All regions ~ 5 yrs

Detector Construct

Detector Install

Pre-Operations

R & D -- Industrialization

Gradient

e-Cloud

System Tests & XFEL

Cryomodule Full Production

Control System challenges

- ***Mainly driven by scale & complexity of ILC accelerators***
  - 100,000 devices, several million control points
  - Main linacs: 640 RF klystrons, 2000 cryomodules, 16,000 cavities
  - Control system: 1000+ front-end crates

- ***Accelerator operations: reliance on automation & feedback***
- ***Accelerator availability goal of 85%*** *(control system: 99%)*
- ***Precision timing & synchronization over 10's km.***
- ***Remote operations.***

- ***ILC funding model: multi-national in-kind contributions.***

Control System functional model

Client Tier

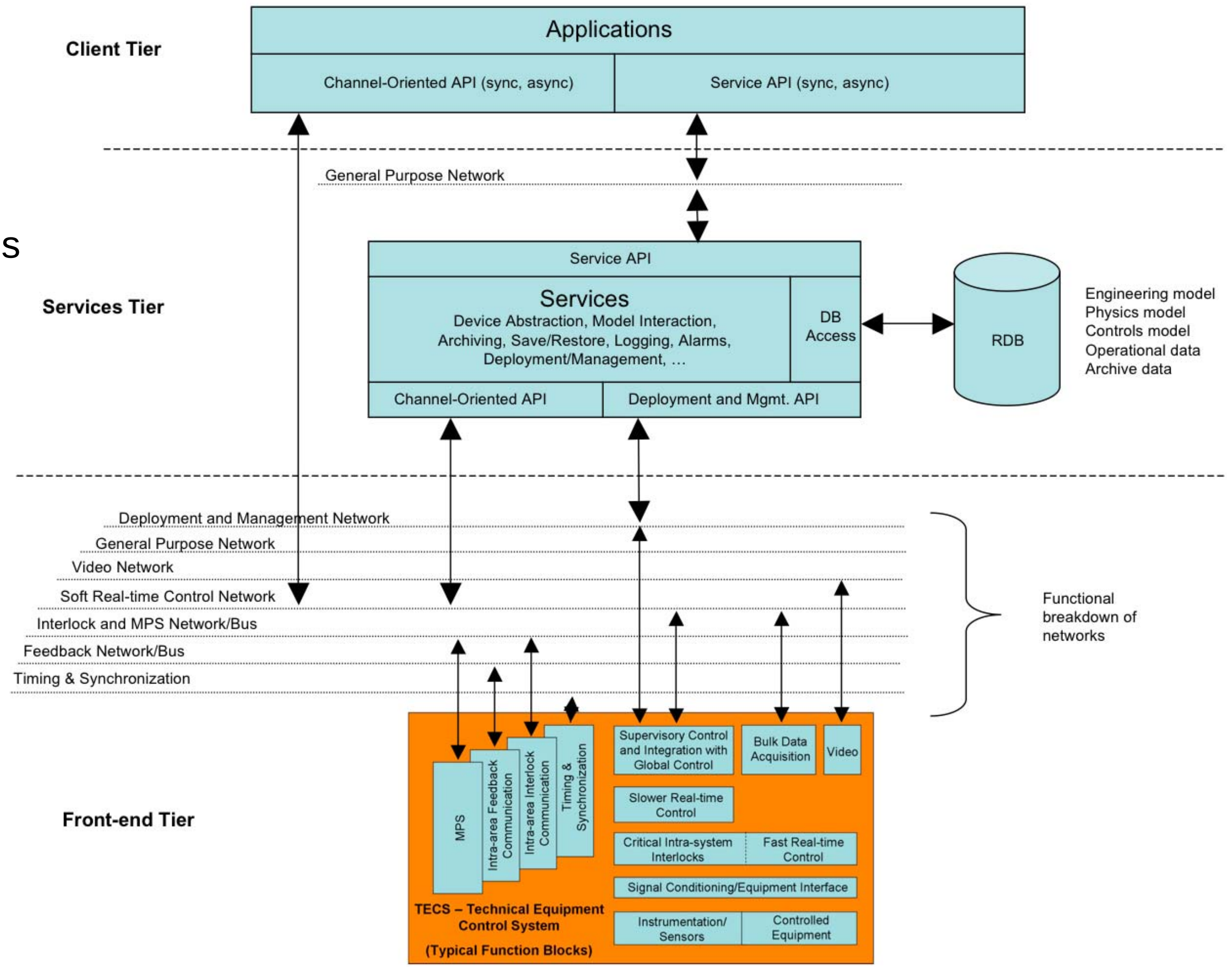
- GUIs
- Scripting
- HMI for high level apps

Services Tier

- "Business logic"
- Device abstraction
- Feedback engine
- State machines
- Online models…

Front-End Tier

- Equipment Interfaces
- Control-point level



Client Tier

Applications

Channel-Oriented API (sync, async)

Service API (sync, async)

General Purpose Network

Services Tier

Service API

Services
Device Abstraction, Model Interaction, Archiving, Save/Restore, Logging, Alarms, Deployment/Management, …

DB Access

RDB

Engineering model
Physics model
Controls model
Operational data
Archive data

Channel-Oriented API

Deployment and Mgmt. API

Deployment and Management Network

General Purpose Network

Video Network

Soft Real-time Control Network

Interlock and MPS Network/Bus

Feedback Network/Bus

Timing & Synchronization

Functional breakdown of networks

Front-end Tier

MPS

Intra-area Feedback Communication

Intra-area Interlock Communication

Timing & Synchronization

Supervisory Control and Integration with Global Control

Bulk Data Acquisition

Video

Slower Real-time Control

Critical Intra-system Interlocks

Fast Real-time Control

Signal Conditioning/Equipment Interface

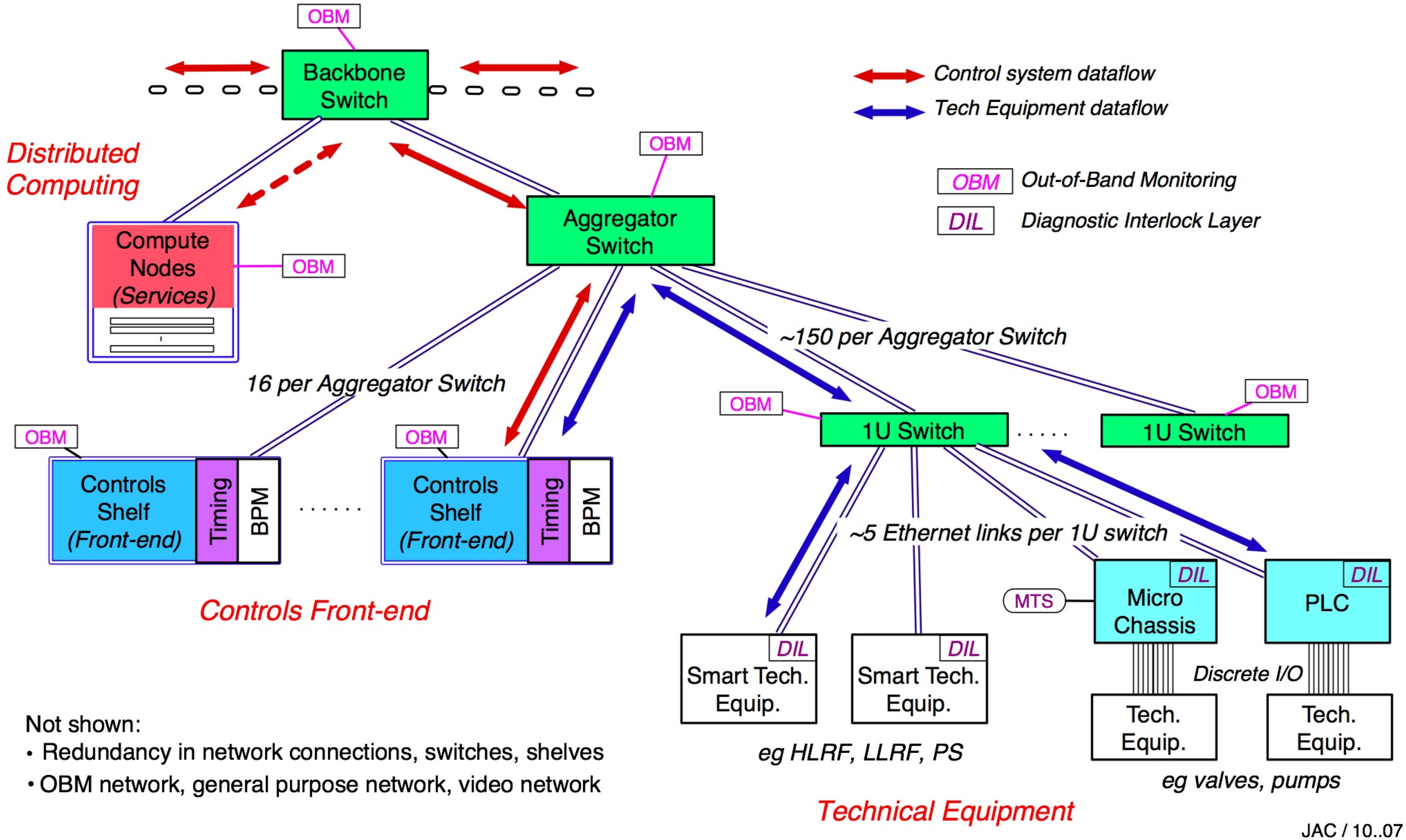
Instrumentation/ Sensors

Controlled Equipment

TECS – Technical Equipment Control System

(Typical Function Blocks)

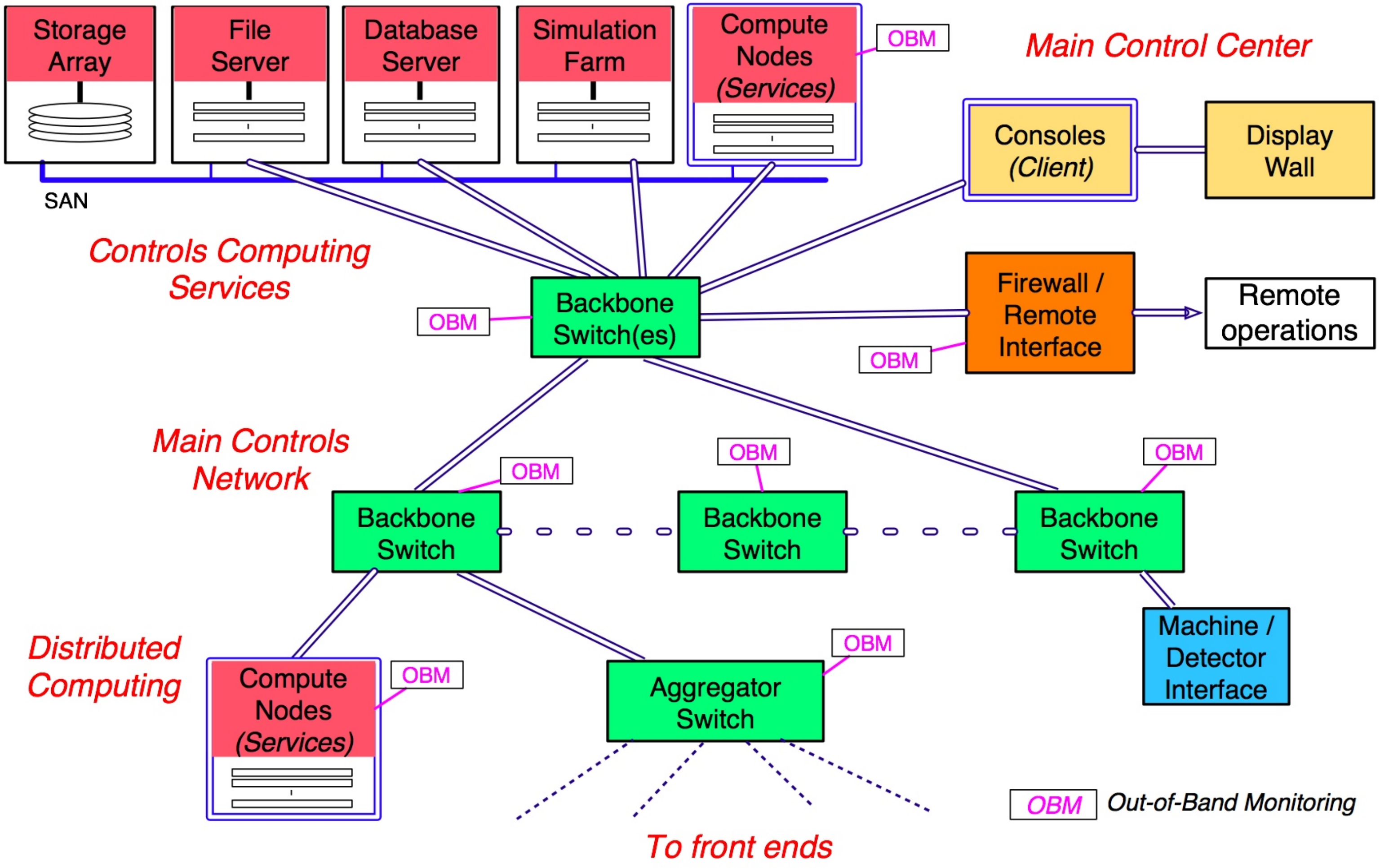
Physical model: front-end



Not shown:

- Redundancy in network connections, switches, shelves
- OBM network, general purpose network, video network

Physical model: global layer



Preliminary component counts

Component	**Description**	**Quantity**
1U Switch	*Initial aggregator of network connections from technical systems*	*8356*
Controls Shelf	*Standard chassis for front-end processing and instrumentation cards*	*1195*
Controls Rack	*Standard rack populated with one to three controls shelves*	*753*
Aggregator Switch	*High-density connection aggregator for 2 sectors of equipment*	*71*
Controls Backbone Switch	*Backbone networking switch for controls network*	*126*
LLRF Controls Station	*Two racks per station for signal processing and motor / piezo drives*	*668*
Phase Ref. Link	*Redundant fiber transmission of 1.3-GHz phase reference*	*68*

Addressing the challenges

- ***Large scale deployment***
  - ***High Availability***, strong emphasis on diagnostics, QA.
  - ***Resource management***
  - Emphasize standards-based solutions.

- ***Extensive reliance on automation and 5Hz feedback***
  - *Automation and feedback engines as* ***Services.***
  - Make all control & monitor points available to feedback engine, synchronize control and monitor actions to 5Hz beam pulses.

- ***Controls integration of in-kind contributed equipment***
  - Scope, span of control, treaty points…
  - ?

Availability

- ***ILC control system availability goal: 99% by design***

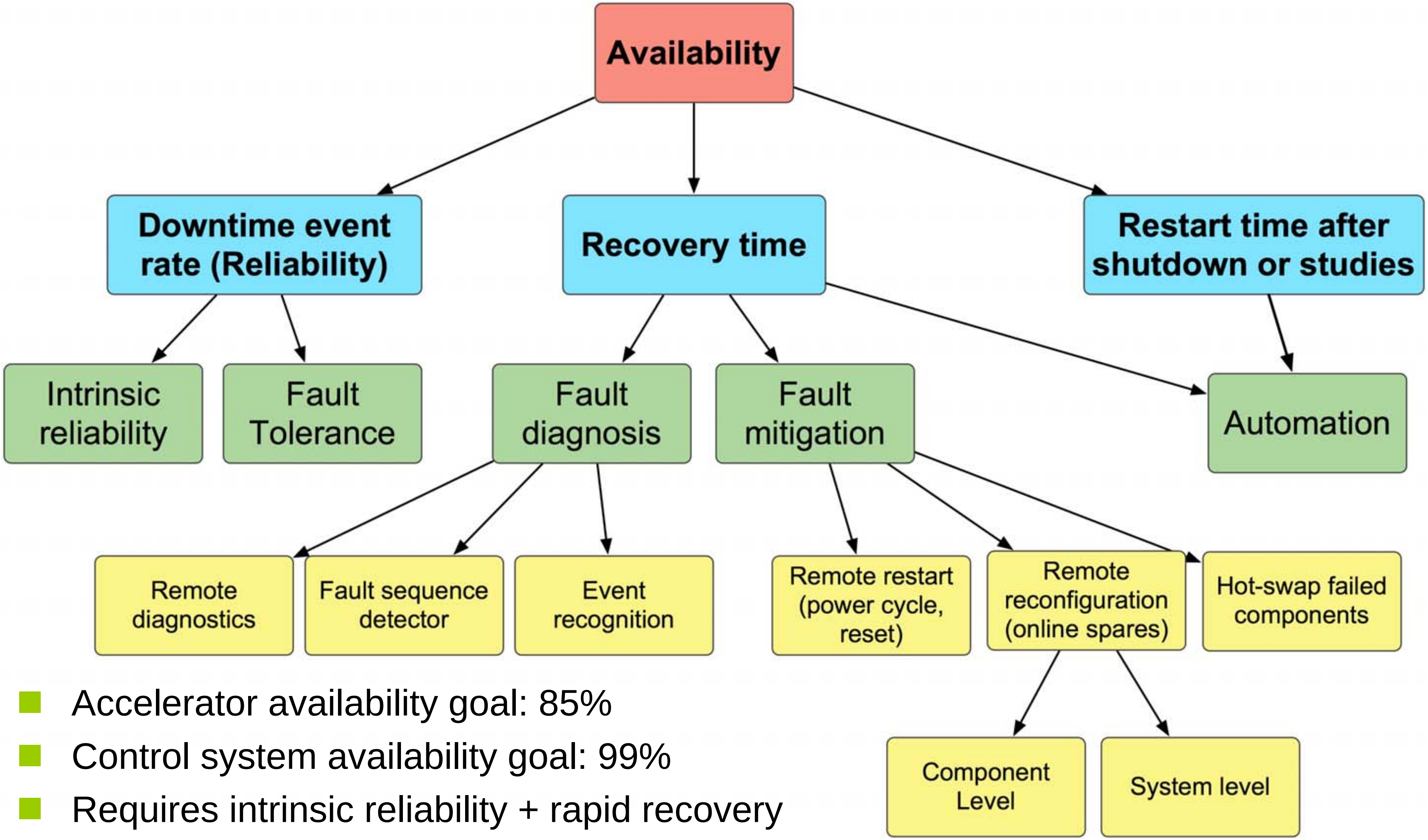
- ***1000+ front-end crates ⇒ 99.999% per crate.***
- ***Cannot afford a long period of identifying & fixing problems once machine operations begin.***

‘Best effort’ approach may not be sufficient

⇓

Investigate High Availability techniques.

Accelerator Availability



- Accelerator availability goal: 85%
- Control system availability goal: 99%
- Requires intrinsic reliability + rapid recovery

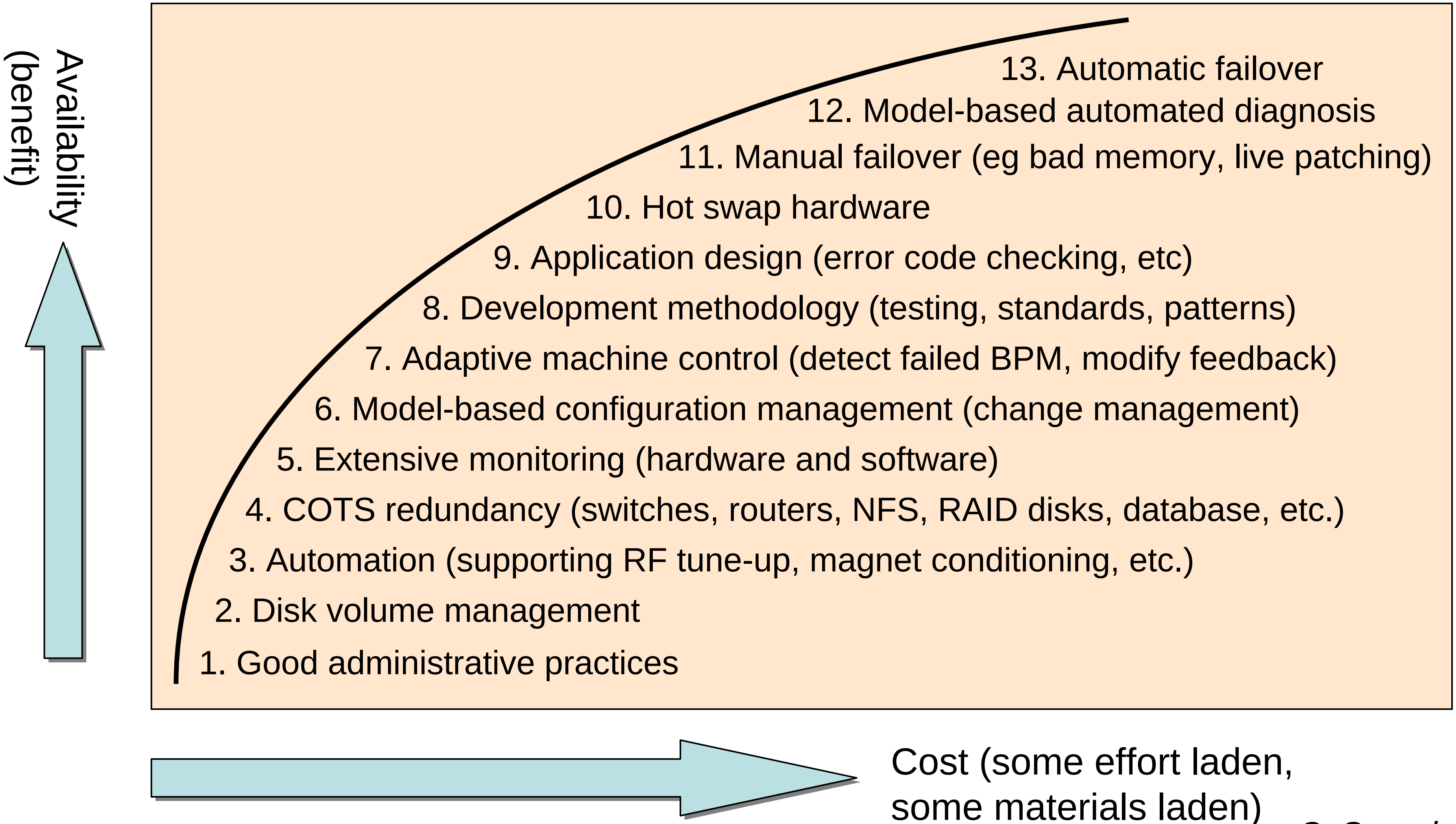
HA requires different considerations

- ***Apply techniques not typically used on an accelerator***
  - Development culture must be different.
  - Cannot build ad-hoc with in-situ testing.
  - Build modeling, simulation, testing, and monitoring into hardware and software methodology up front.

- ***Hardware availability***
  - Instrumentation electronics to servers and disks.
  - Redundancy where feasible, otherwise adapt in software.
  - Modeling and simulation

- ***Software availability***
  - Equally important.
  - Software has many more internal states – difficult to predict.
  - Modeling and simulation needed here for networking and software.
  - Robustness
  - Exception handling.

Relative cost/benefit of HA techniques



13. Automatic failover

12. Model-based automated diagnosis

11. Manual failover (eg bad memory, live patching)

10. Hot swap hardware

9. Application design (error code checking, etc)

8. Development methodology (testing, standards, patterns)

7. Adaptive machine control (detect failed BPM, modify feedback)

6. Model-based configuration management (change management)

5. Extensive monitoring (hardware and software)

4. COTS redundancy (switches, routers, NFS, RAID disks, database, etc.)

3. Automation (supporting RF tune-up, magnet conditioning, etc.)

2. Disk volume management

1. Good administrative practices

Availability (benefit)

Cost (some effort laden, some materials laden)

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HA R&D objectives

- ***Learn about HA (High Availability) in context of accelerator controls***
  - Bring in expertise (RTES, training, NASA, military, …)
  - Explore standards-based methodologies

- ***Develop (adopt) a methodology for examining control system failures***
  - Fault tree analysis, FMEA, scenario-based FMEA
  - Others…

- ***Develop policies for detecting and managing failure modes***
  - Development and testing methodology
  - Instrumentation, out-of-band monitoring (independent diagnostics)
  - Workarounds
  - Redundancy

- ***Develop "vertical" prototypes***
  - Ie. how we might implement above policies
  - Integrate portions of "vertical" prototypes with accelerator facilities

Front-end electronics requirements

- ***HA-specific requirements***
  - Intelligent Platform Management
  - Remote power on/off and reset/initialize for individual boards.
  - Highly improved diagnostics capabilities in all electronics subsystems.
  - Support redundancy: processors, comms links, power supplies,…
  - Hot-swappable components: circuit boards, fans, power supplies, …

- ***Platform basic requirements***
  - Standard modular architecture
  - Broad industry support of core components
  - Wide range of COTS modules + support custom instrumentation.
  - ‘High performance’ + cost-effective.

If not VME or VXI, then what…?

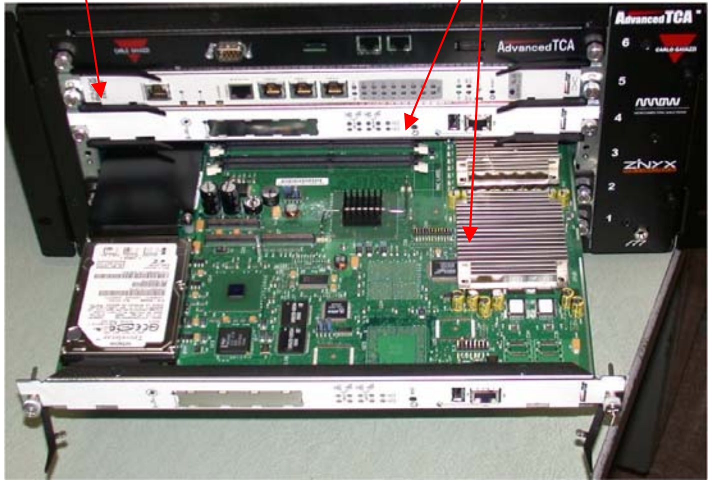
- ***Candidate standards include ATCA, uTCA, VME64x, VXS, VPX, other VITA standards…***

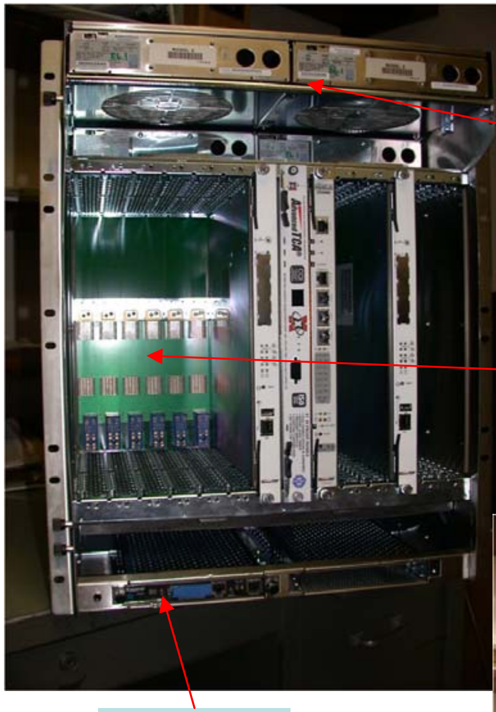
- ***Of systems available today, ATCA offers the best representative feature set***
  - Represents best practices of decades of telecom platform development.
  - Increasing evidence of commercial products for controls applications.
  - Growing interest in the Controls and DAQ community.
  - Being evaluated by several labs. Strong candidate for XFEL.

- ***Two flavors***
  - ATCA: Full-featured, large form-factor
  - uTCA: Reduced feature-set, smaller form-factor, lower cost.

ATCA crates

5-Slot Crate w/ Shelf Manager
Fabric Switch
Dual IOC Processors





4 Hot-Swappable Fans

16 Slot Dual Star Backplane

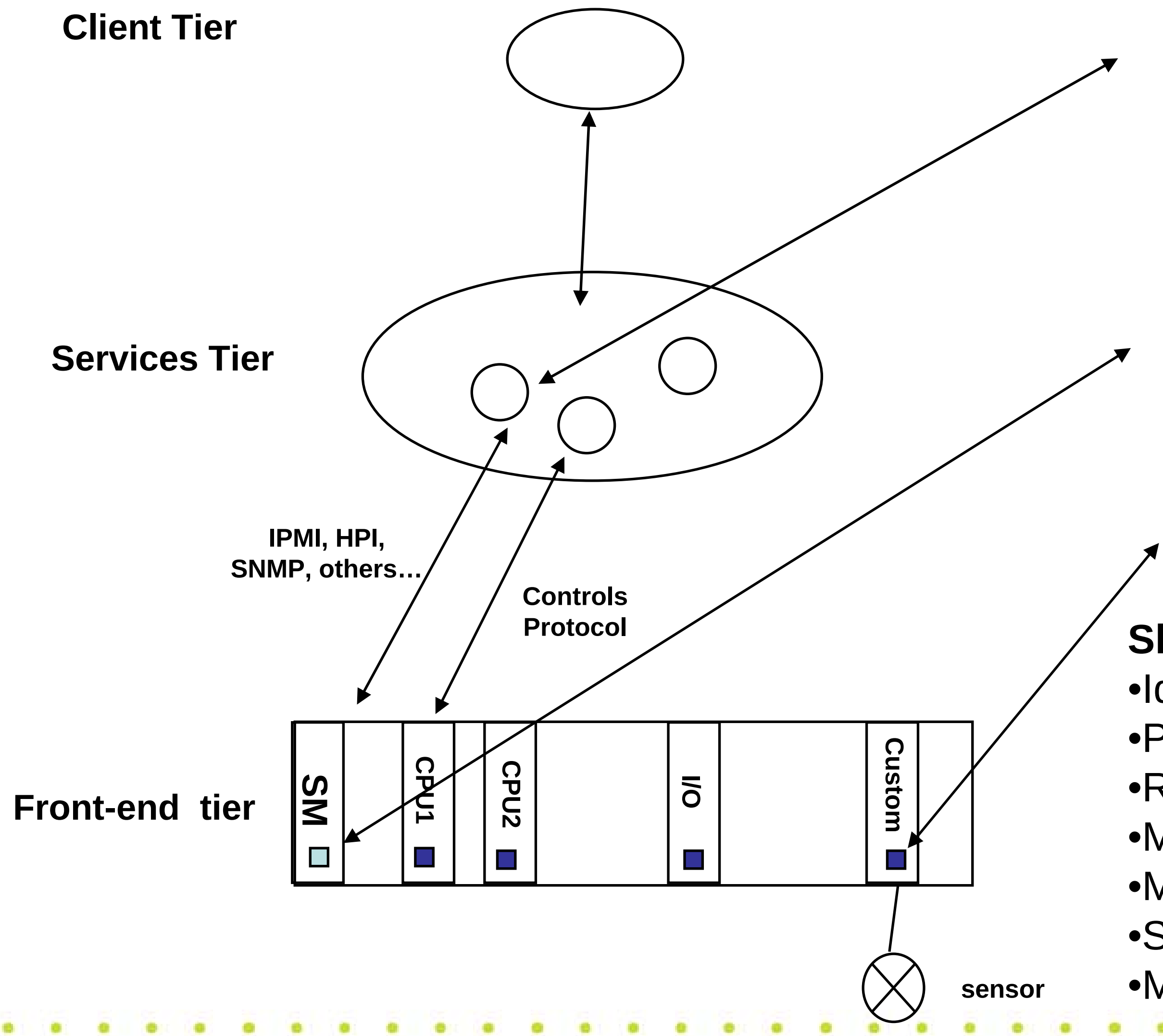
Shelf Manager

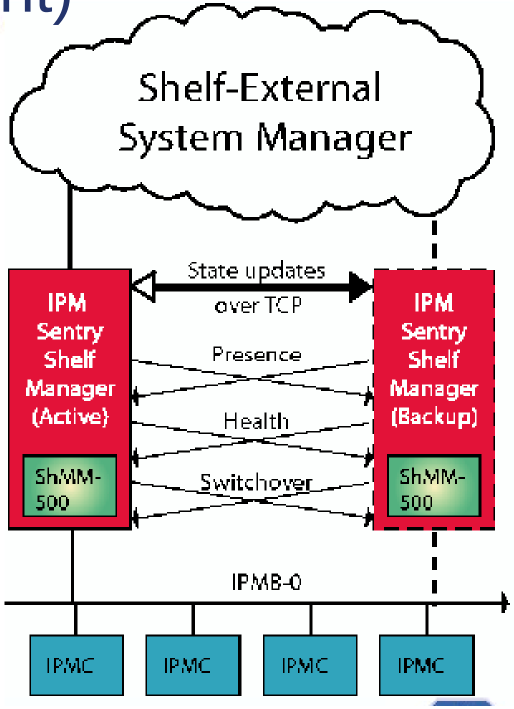
Dual IOC's
Fabric Switch

Dual 48VDC
Power Interface

Rear View

Fault detection and remediation
(“Shelf” Management)




Shelf-External System Manager
State updates over TCP
IPM Sentry Shelf Manager (Active)
ShMM-500
Presence
Health
Switchover
IPM Sentry Shelf Manager (Backup)
ShMM-500
IPMB-0
IPMC
IPMC
IPMC
IPMC

Shelf Manager:

- Identify all boards on shelf
- Power cycle boards (individually)
- Reset boards
- Monitor voltages/temps
- Manage Hot-Swap LED state
- Switch to backup flash mem bank
- More…

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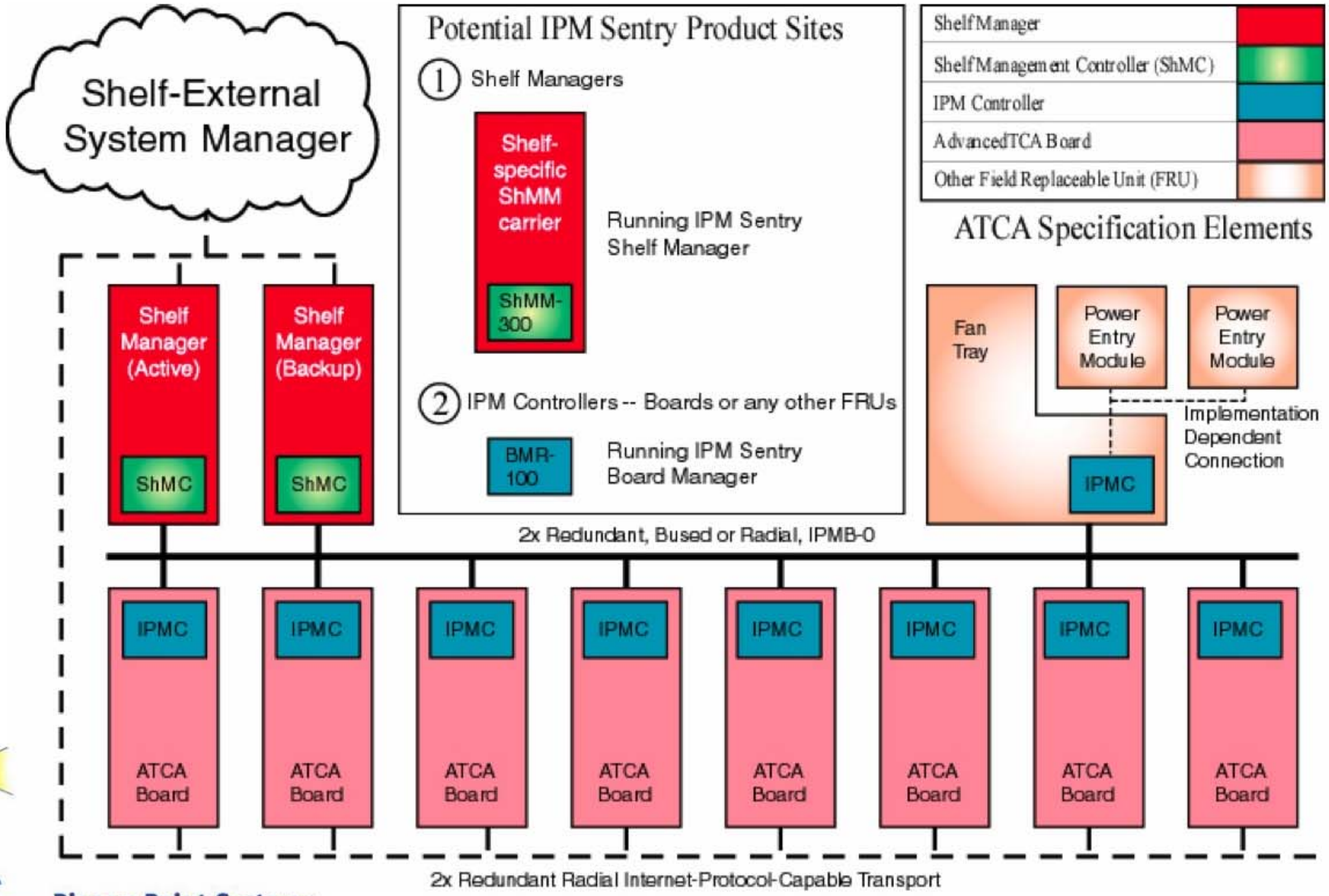
ATCA Shelf w/ Dedicated Shelf Management Controllers



Shelf-External System Manager

Shelf Manager (Active)

ShMC

Shelf Manager (Backup)

ShMC

Potential IPM Sentry Product Sites

1. Shelf Managers

Shelf-specific ShMM carrier

ShMM-300

Running IPM Sentry Shelf Manager

2. IPM Controllers -- Boards or any other FRUs

BMR-100

Running IPM Sentry Board Manager

Shelf Manager	🟥
Shelf Management Controller (ShMC)	🟩
IPM Controller	🟦
AdvancedTCA Board	🟥
Other Field Replaceable Unit (FRU)	🟧

ATCA Specification Elements

Fan Tray
Power Entry Module
Power Entry Module
Implementation Dependent Connection
IPMC
2x Redundant, Bused or Radial, IPMB-0
IPMC
ATCA Board
2x Redundant Radial Internet-Protocol-Capable Transport

Pigeon Point Systems

SAF Availability Management Framework

- ***Open standard from telecom industry geared towards highly available, highly distributed systems.***

- *Manages software runtime lifecycle, fault reporting, failover policies, etc.*
- *Works in combination with a collection of well-defined services to provide a powerful environment for application software components.*

- ***Potential application to critical core control system software such as IOCs, device servers, gateways, name-servers, data reduction, etc.***

- ***Know exactly what software is running where.***
- ***Gracefully restart components, manage state for component hot-swap***
- ***Uniform diagnostics to troubleshoot problems.***

- ***Implementations: OpenClovis, OpenSAF, Self-Reliant, Element, …***

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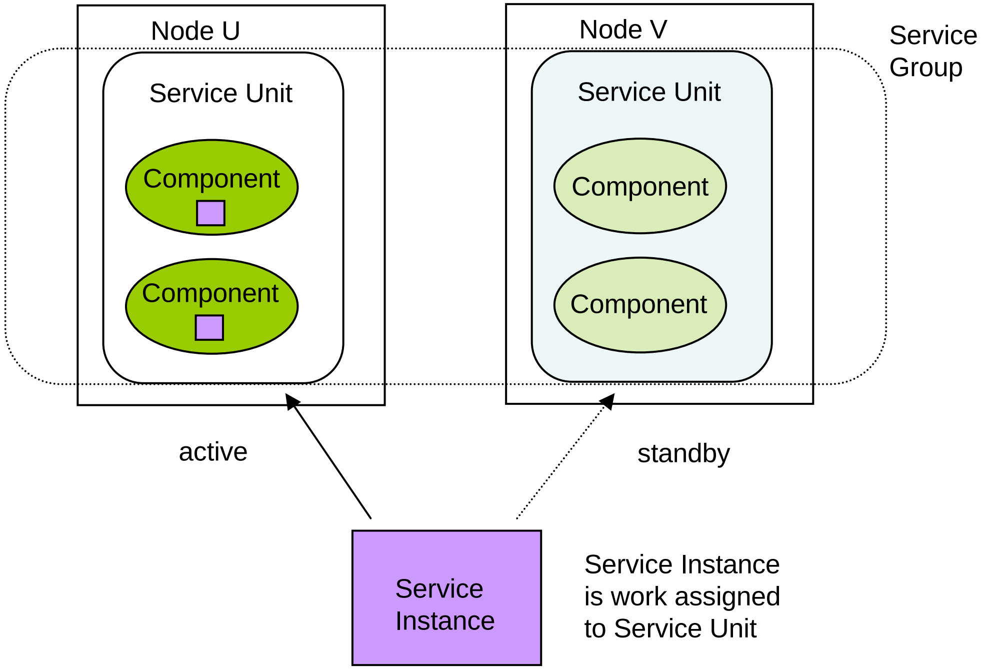
SAF – Availability Management Framework

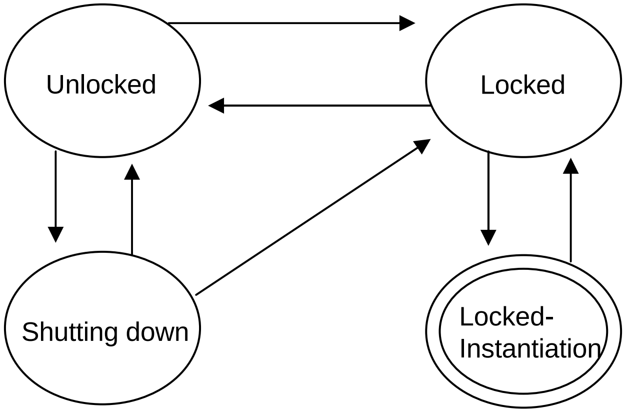
A simple example of software component runtime lifecycle management

AMF Logical Entities



Service Instance is work assigned to Service Unit

Service Unit Administrative States



1. Service unit starts out un-instantiated.

2. State changed to locked, meaning software is instantiated on node, but not assigned work.

3. State changed to unlocked, meaning software is assigned work (Service Instance).

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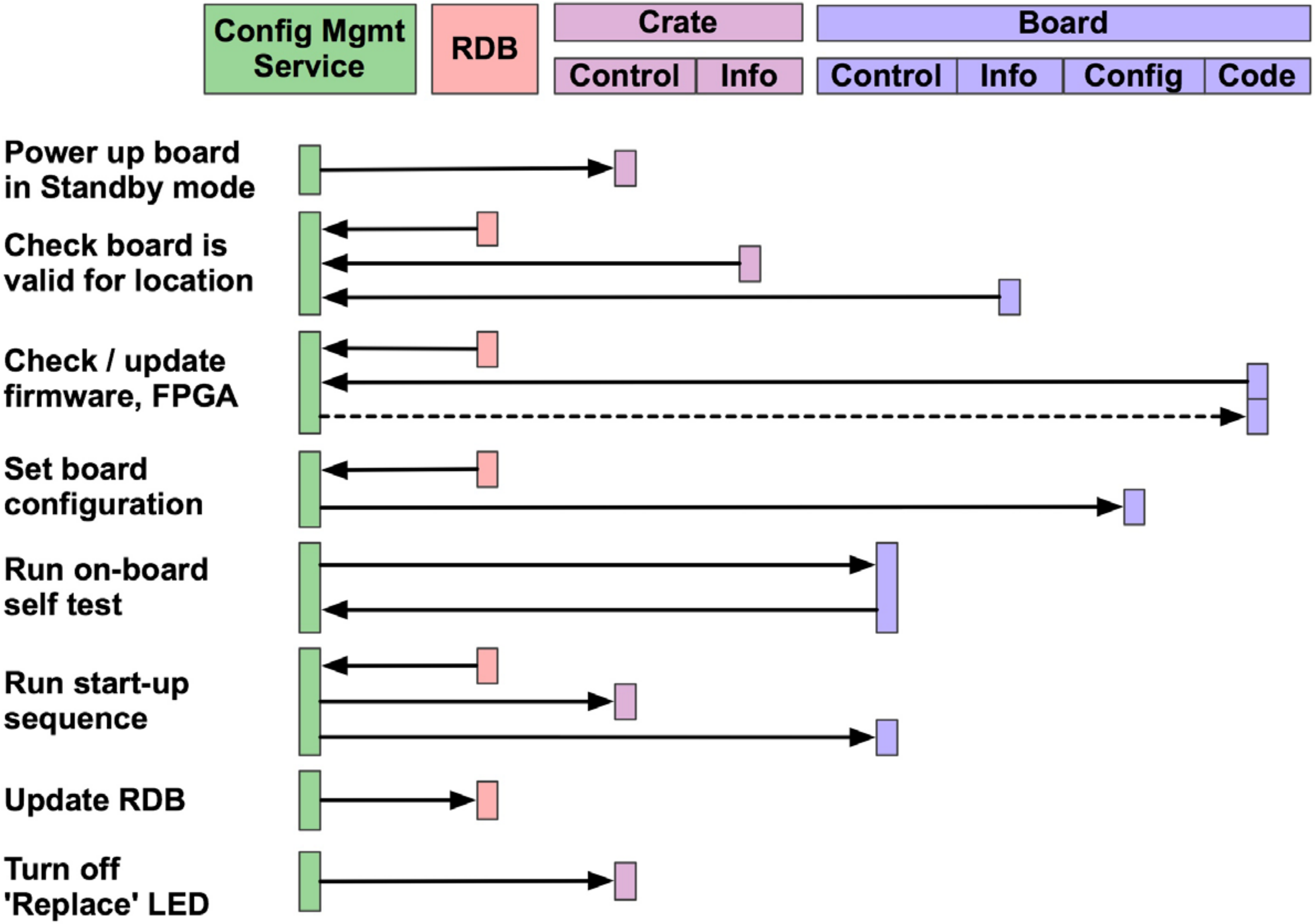
HA software framework is just the start

- ***SAF (Service Availability Forum) implementations won't "solve" HA problems***
  - You still have to determine what you want to do and encode it in the framework – **this is where work lies**
    - What are failures
    - How to identify failure
    - How to compensate (failover, adaptation, hot-swap)
- ***Is resultant software complexity manageable?***
  - Potential fix worse than the problem
  - Always evaluate: "am I actually improving availability?"
- ***Where should we apply high availability techniques?***

Configuration management

Example: replacing circuit board



…underlying assumptions

- ***Electronics board functions:***
  - Hot-swappable
  - Remote reset / re-initialize.
  - Unique ID, available remotely
  - Remotely configurable (“DIP switches”)
  - Remotely updatable software, firmware, FPGA code
  - Separate Standby and Run modes
  - On-board self-test

- ***RDB contains:***
  - Information on all installed and spare electronics boards
  - Information for every crate / slot / location
  - Current version of all software, firmware, FPGA code

Services Tier architecture

Applications

Graphical interfaces

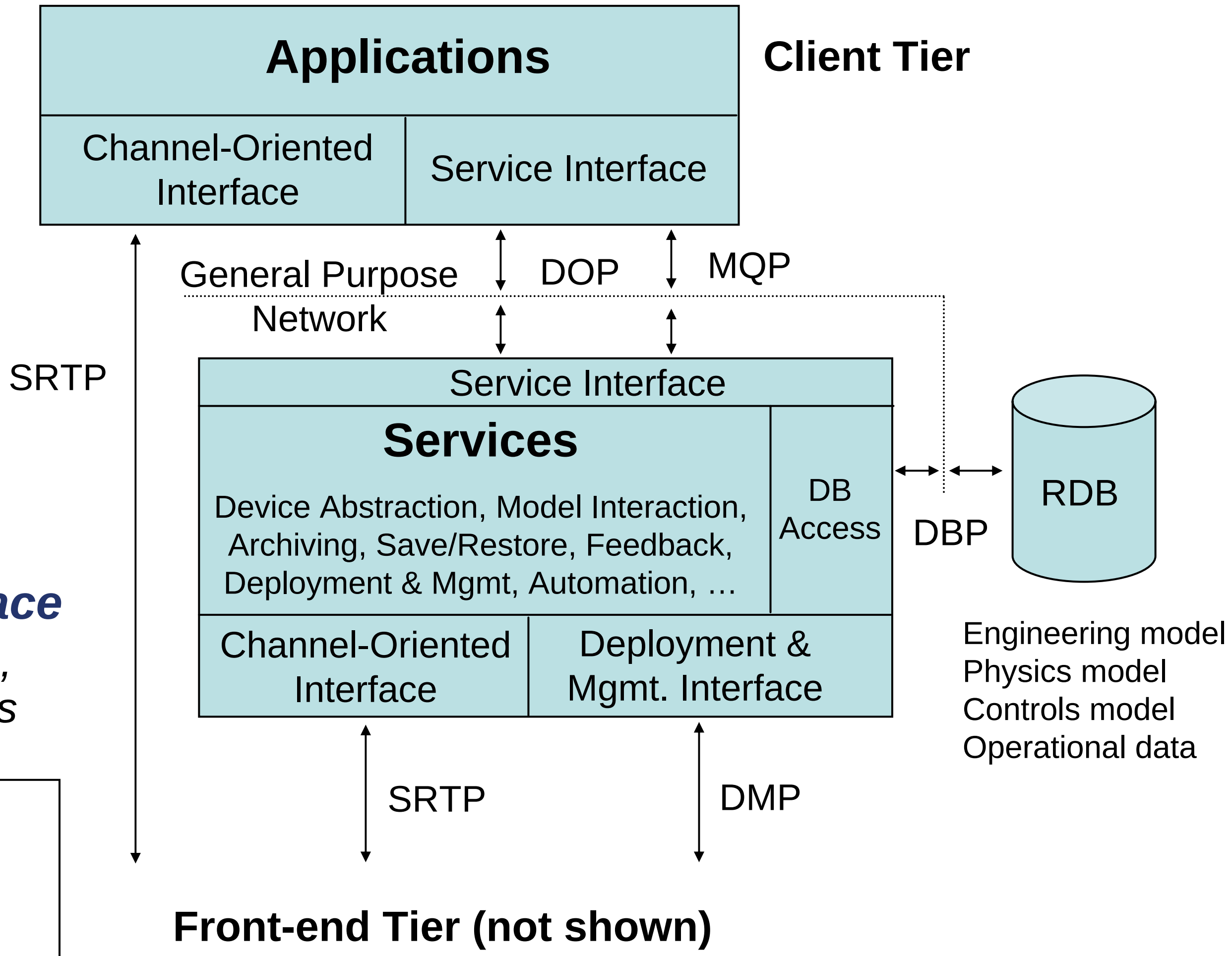
Operator consoles

Services

Well defined high-level functions available to any application or other service

Channel-oriented Interface

Traditional high-performance, direct access to control points



Applications
Channel-Oriented Interface
Service Interface
Client Tier
General Purpose Network
DOP
MQP
SRTP
Service Interface
Services
Device Abstraction, Model Interaction, Archiving, Save/Restore, Feedback, Deployment & Mgmt, Automation, …
DB Access
DBP
RDB
Channel-Oriented Interface
Deployment & Mgmt. Interface
SRTP
DMP
Engineering model
Physics model
Controls model
Operational data
Front-end Tier (not shown)

DOP – distributed object protocol

MQP – message queuing protocol

SRTP – soft real-time protocol

DBP – database protocol

DMP – deployment & mgmt protocol

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Why Services?

- ***Some activities are not well suited to channel-oriented interfaces***
  - **Complex**
    - May require lots of parameters and a sequence of interactions
  - **Dynamic**
    - May be added and removed frequently during operations
    - May require dynamic allocation (network latency and/or cpu loading)
  - It should be possible to create a well-defined interface for common control system functions.

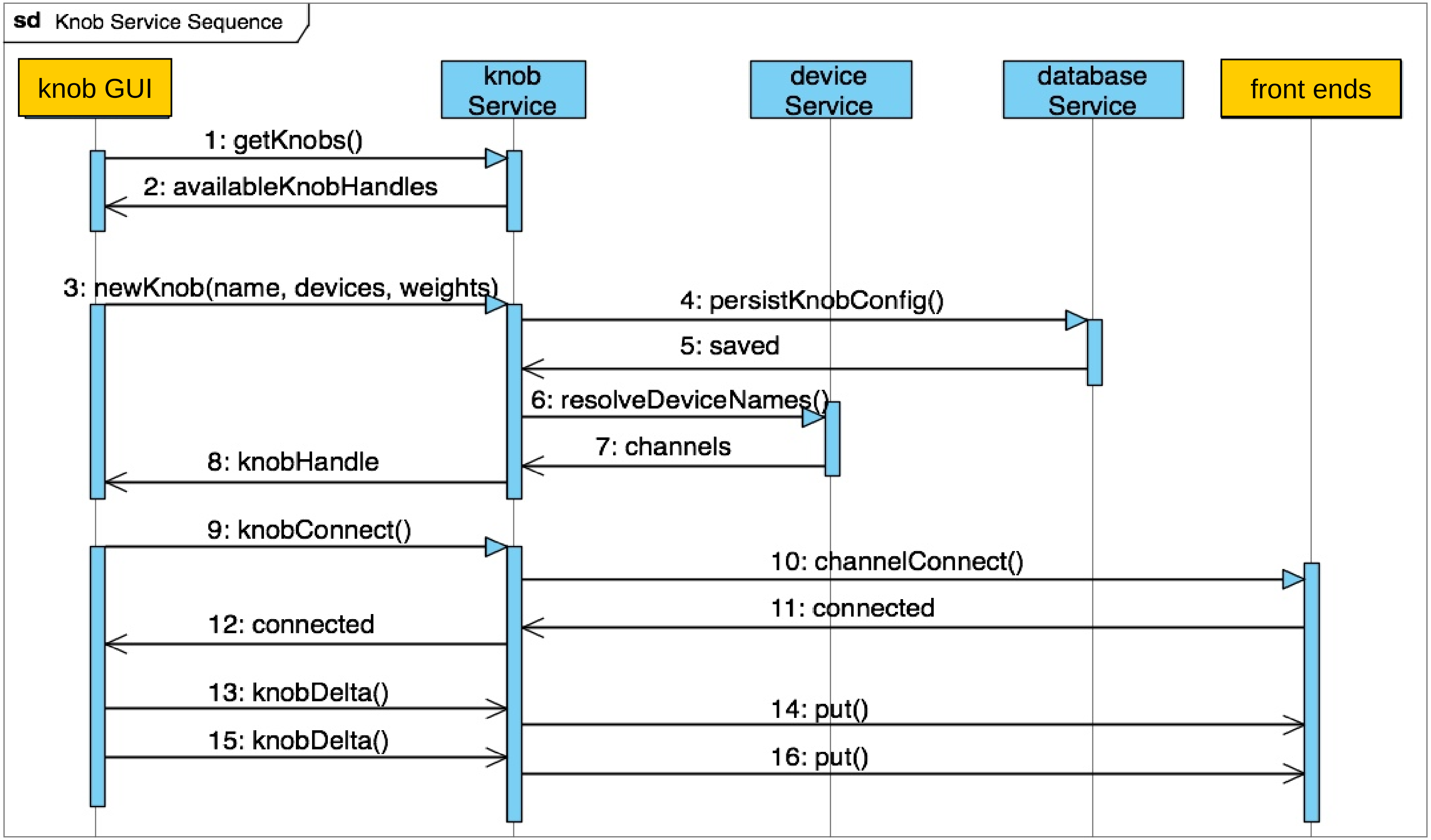
- ***Services allow rapid prototyping of high level apps through composition, while maintaining an an impedance to changing the core functions.***

- ***Someone is going to do this anyway***

Possible Services APIs

- *Script execution service*
- *Archiving service*
- *Logging service*
- *Data processing & visualization*
- *Save, Compare, Restore*
- *Alarm Management*
- *RDB calls*
- *Locking (channel, instance,…)*
- *Math & logic functions*
- *Event sequencer / synchronizer*
- *Device server*
- *Data concentrator*
- *Feedback / dynamical control*
- *Video processing, compression*
- *Out of Band monitoring*
- *Exception handling*
- *Resource management*
- *Authentication / access control*
- *Notification (email, phone, sms,…)*

Example: Knob Service Sequence



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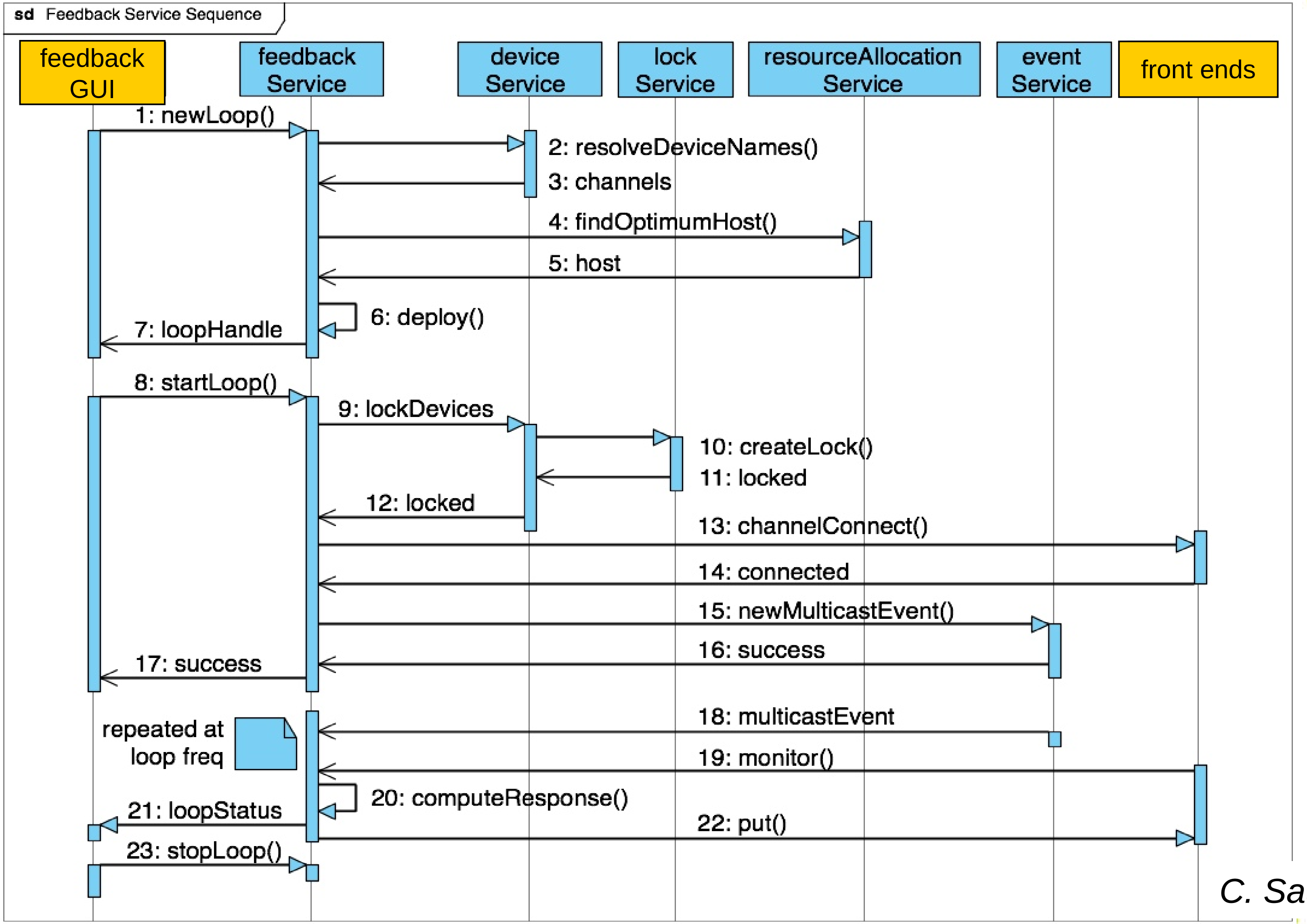
Example: Feedback Service Sequence



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Services Tier realization…

- ***Defining a Services Tier does not define where it runs***
  - Front-end processors
  - Client workstations
  - Dedicated processors
  - Central servers

- ***Interfaces are hard to define***
  - API inputs, outputs.
  - Services dependencies.

Collaboration

- ***Inherently an international collaboration***
  - Resource-limited (2-3 FTEs)
  - Main collaborators: Argonne, DESY, Fermilab, KEK, SLAC
- ***Heavily reliant on activities at new and operating accelerators***
  - Benefit from existing work.
  - Prototype & evaluate ideas and techniques.
- ***Strong connection with DESY XFEL, Fermilab ILCTA, KEK STF***
- ***We need more people to support the Global Design Effort, contribute ideas, collaborate in developing & evaluating ideas.***

2008-2010 Work Package topics

- *Electronics platform evaluations (eg ATCA, uTCA)*
- *High Availability*
- *Risk analysis of design, FMEA*
- *Services architecture development*
- *Integrated software development on an international scale*
- *Configuration management*
- *Control System architecture design*
- *Network simulation/modeling*
- *Machine protection*
- *Remote Operations*
- *Evaluate potential controls integration tools*
- *Cost optimization*
- *Controls integration*

Wrap-up

- We have identified technical challenges that can be pursued now, and have created work packages that describe ways to address them.

- There is more work than a few FTEs can do

  …we are looking for more collaborators

ILC: www.linearcollider.org

Controls: www.linearcollider.org/wiki