Requirements Engineering for Control and Computing Systems at large research facilities: Process implementation and a case study

Thilo Friedrich

Miha Reščič

Prof. Martin Törngren

www.europeanspallationsource.se

4 August 2015

Who we are

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Thilo Friedrich

- Systems and Standardization Engineer
- European Spallation Source ESS, controls division
- PhD student at the Royal Institute of Technology, KTH Stockholm, Dept. of Machine Design

KTH VETENSKAP OCH KONST

Miha Reščič

- Deputy Project Manager, Lead Systems Engineer
- European Spallation Source ESS, controls division

Prof. Martin Törngren

- Royal Institute of Technology Stockholm, KTH Stockholm, Dept. of Machine Design

Requirements Engineering for Control and Computing Systems at large research facilities: Process implementation and a case study

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- Our field of interest:
  - Requirements Engineering & Systems Engineering for Controls and Computing Systems at large research facilities
  - case study environment:
    - European Spallation Source ESS
    - controls and computing systems

- RE implementation approach
  - characterisation of RE implementation in our domain
  - implementation approach
  - understanding obstructions
  - agile concept for process implementation

- Our case study findings
  - results and conclusions

Visiting the Particle Accelerator Zoo, we see a lot of large, strange beasts…

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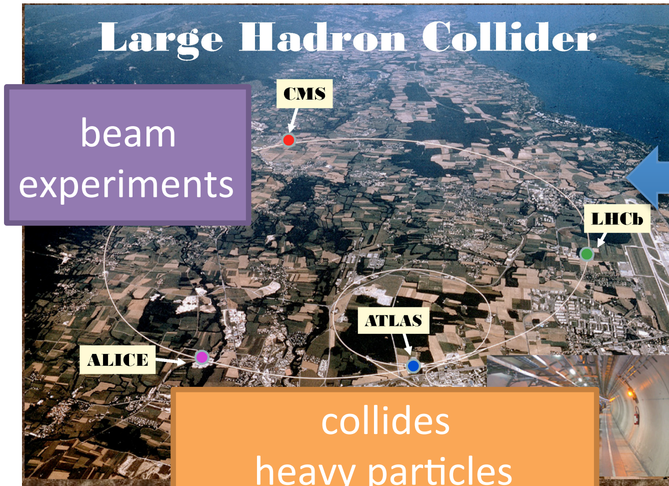
LHC at CERN. Geneva, Switzerland

DESY, European XFEL. Hamburg, Germany.

MAX IV Laboratory. Lund, Sweden.

European Spallation Source ESS.
Lund, Sweden.

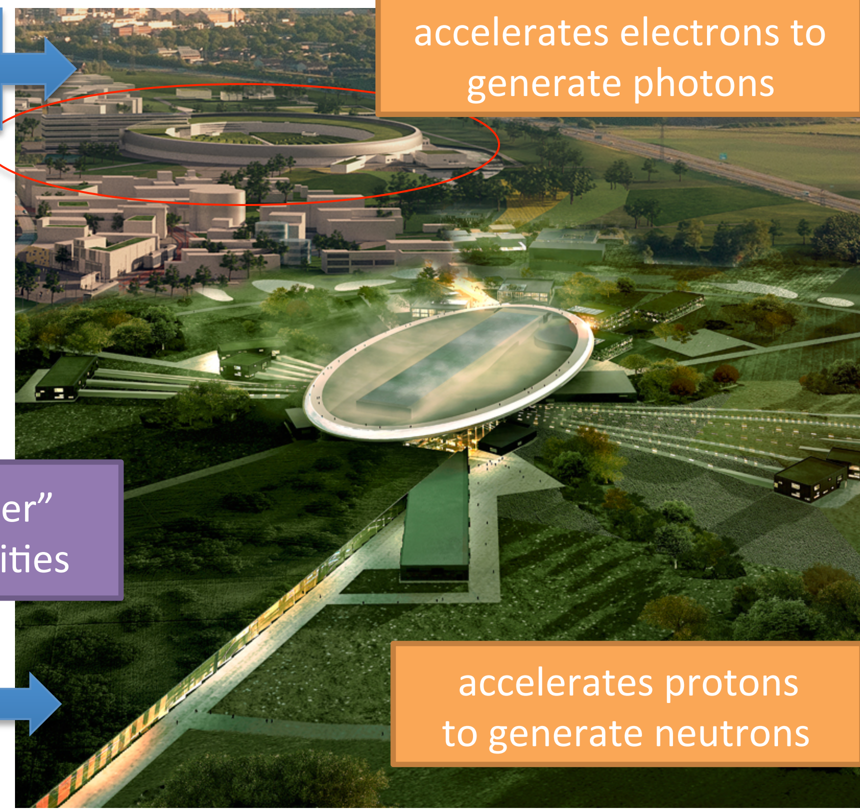
Visiting the Particle Accelerator Zoo, we see a lot of large, strange beasts...



LHC at CERN. Geneva, Switzerland

Synchrotron rings

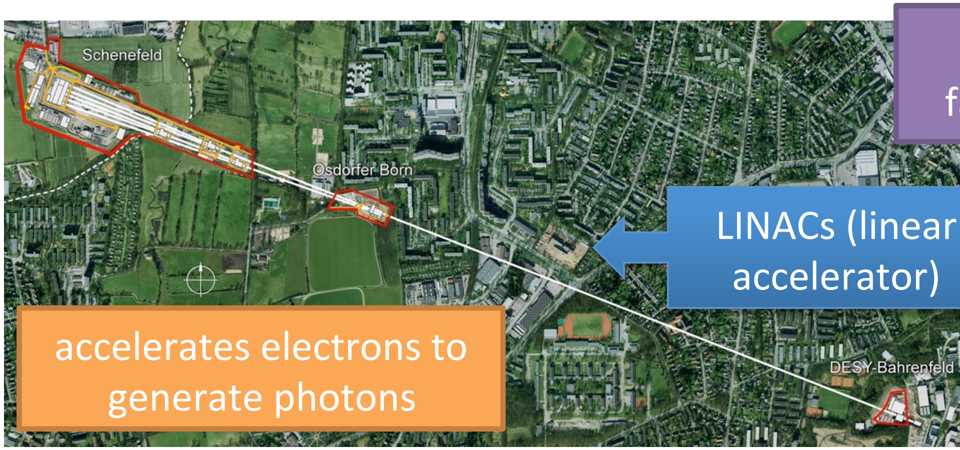
MAX IV Laboratory. Lund, Sweden.



European Spallation Source ESS. Lund, Sweden.

"user" facilities

LINACs (linear accelerator)



DESY, European XFEL. Hamburg, Germany.

European Spallation Source ESS

ESS enables world-leading science

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ESS will be the most powerful spallation source with the highest flux and realtime data acquisition.

- Life sciences
- Soft condensed matter
- Chemistry of materials
- Energy research
- Magnetism and superconductivity
- Engineering materials and geosciences
- Archeology and heritage conservation
- Fundamental and particle physics

How are these people helped by Material Science


Pace Maker
Li-Batteries
New Materials for Energy
GPS Navigation
Functional Materials
Air Bag
Accelaration Sensors
MEMS
Cosmetics
TiO_2 Nanoparticle
Artificial Lens
Biocompatible polymers
Glasses & Coatings
Optical Materials
UV Filter
Artificial Hips
Biocompatible Materials
Mobile Phone
SAW structures
Digital Camera
CCD Chip
Bike Frame
Carbon Fibres
Composite Materials
GMR Read Head
Magnetic Multilayers
LED Display
Photonic Materials
Intelligent Credit Card
Integrated Circuits
Exact Time via satellite
Semiconducting devices
Micro-Batteries

Science institutions involved in the design & construction of ESS

Aarhus University
CEA Saclay, Paris
CNRS Orsay, Paris
ESS Bilbao
INFN, Catania
Lund University
Uppsala University
Accelerator Science and Technology Centre, Daresbury and Oxford
CERN, Geneva
Cockcroft Institute, Daresbury
DESY, Hamburg
ESS Bilbao
Fermi National Laboratory, Chicago

John Adams Institute for Accelerator Science, London and Oxford
Laval University, Canada
Maribor University, Slovenia
National Centre for Nuclear Research, Poland
Oslo University
Rostock University
Spallation Neutron Source, Oak Ridge
Stockholm University
Techical University of Darmstadt
Nuclear Physics Institute Of The Ascr
Czech Technical University, Prague
Aarhus University
University Of Copenhagen
University Of Southern Danmark
Technical University Of Danmark - Dtu
Institut Laue-Langevin - Ill
Llb (Laboratoire Léon Brillouin)
Helmholtz-Zentrum, Berlin
Helmholtz-Zentrum, Geesthacht
Technical University, Munich
Forschungszentrum, Jülich
Elettra-Sincrotrone Trieste
Università Di Perugia
Consiglio Nazionale Delle Ricerche
Delft University Of Technology
Institute For Energy Technology, Ife
Linköping University
Mid Sweden University
Epfl | École Polytechnique Fédérale De Lausanne
Paul Scherrer Institute, Psi

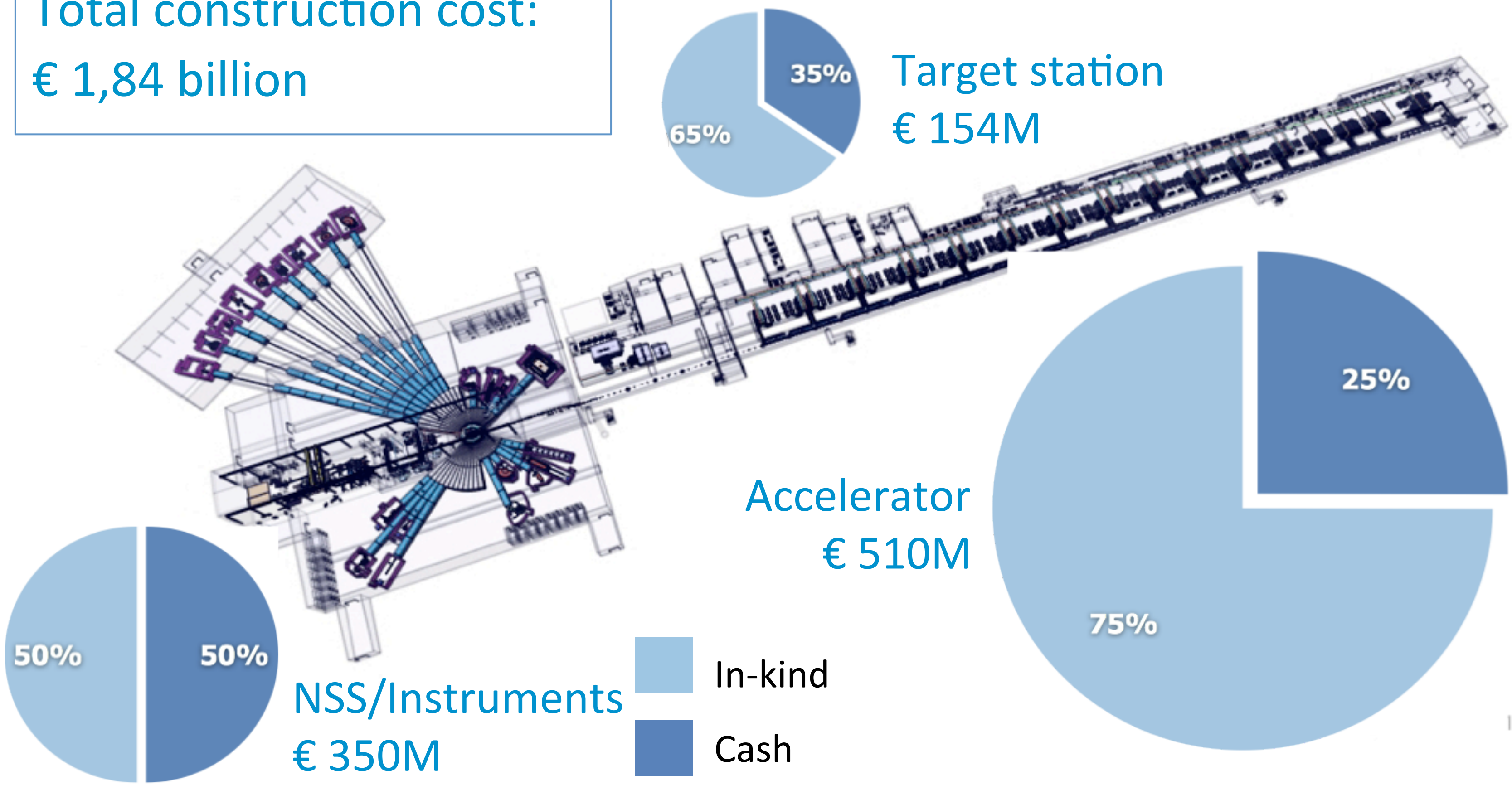
In-kind contributions:

Design & build off-site, ship & install in Lund

Schematic ESS
Cost and in-kind contributions

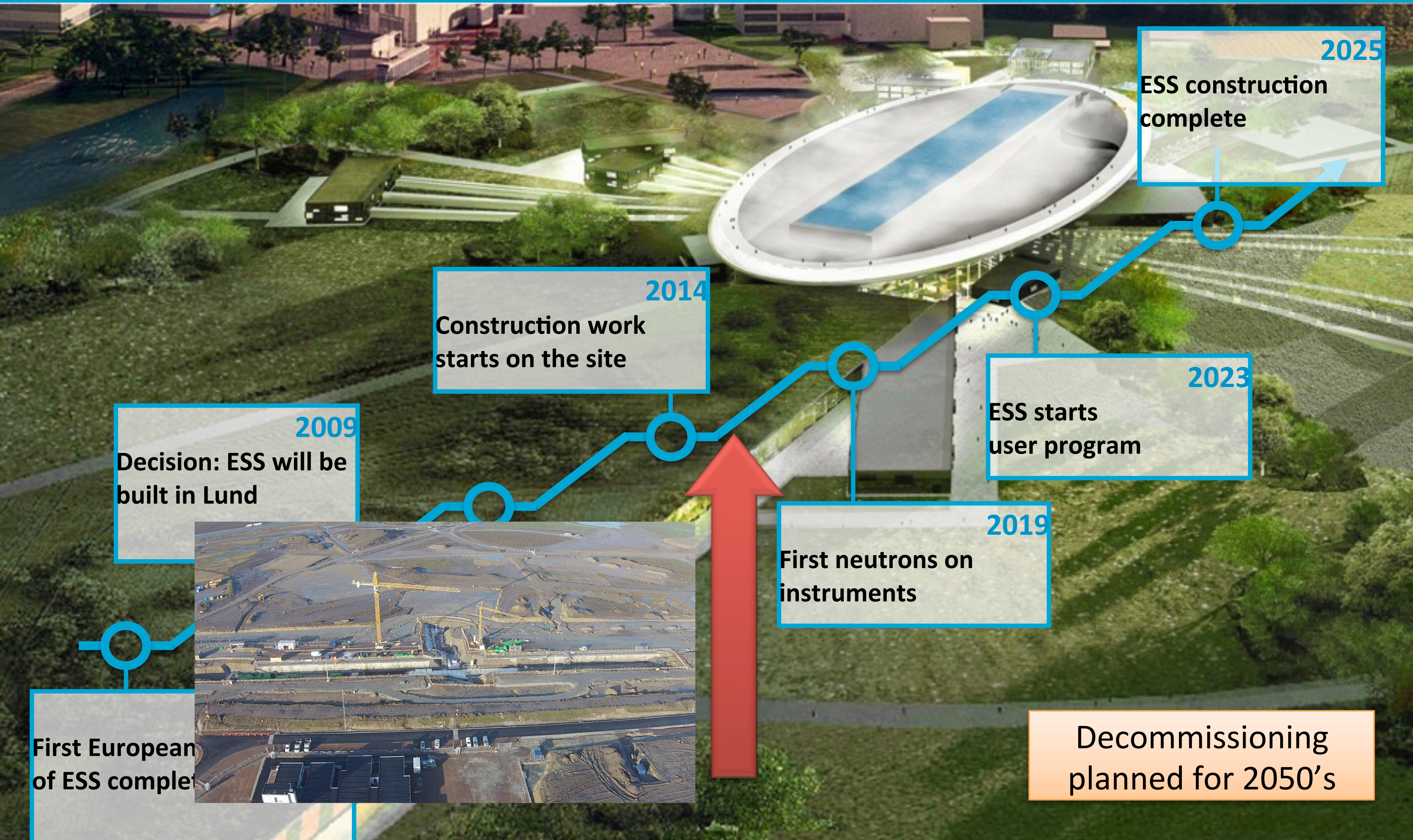
Total construction cost:

€ 1,84 billion



-> Integration challenge!

Road to realizing the world's leading facility for research using neutrons



Accelerator based research facilities need controls and computing systems ...

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... concerning e.g.

- Magnet systems
- Radiofrequency systems
- Ultra-high vacuum systems
- Particle beam diagnostics
- Timing / synchronization systems
- Conventional systems (HVAC, water, electric power)
- Personnel safety (radiation, access, high voltage, ...)
- Machine Protection (immense beam power)
- Experiment installations
- Data acquisition and analysis
- ...

Accelerator based research facilities need controls and computing systems (1)

- distributed controls
  - PLCs, servers, controllers
  - ESS: x-thousands distributed 'devices'

Accelerator based research facilities need controls and computing systems (2)

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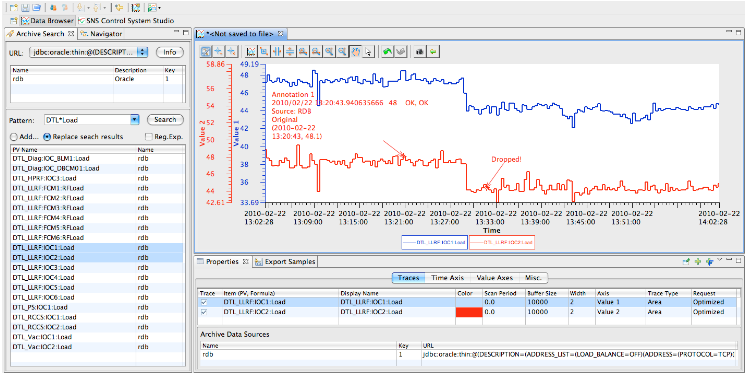
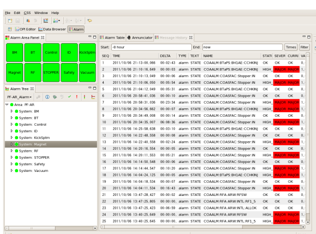
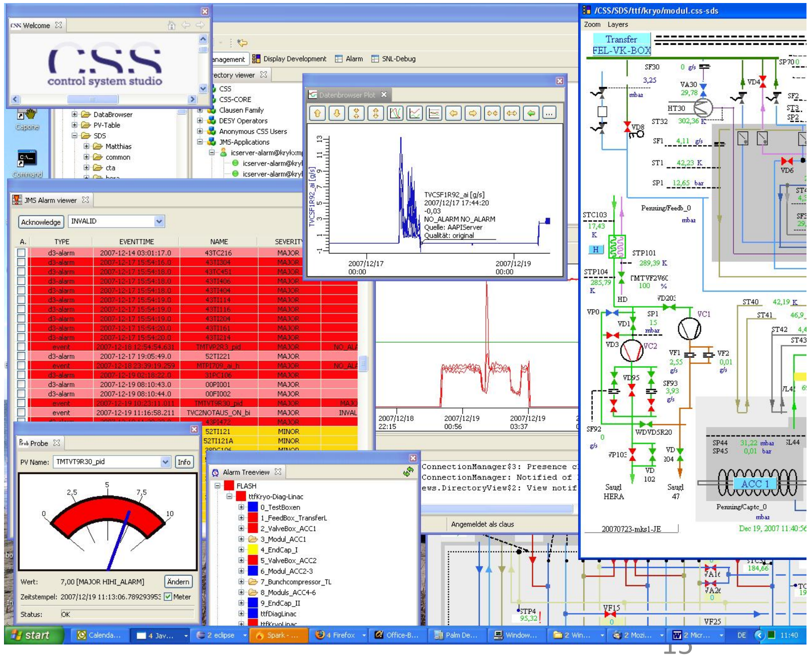
- facility integration
  - Supervisory Control and Data Acquisition (SCADA)
  - control room, remote access
  - ESS: estimated 500.000 – 1 million ‘data points’
  - Services for
    - archiving, machine analysis
    - configuration







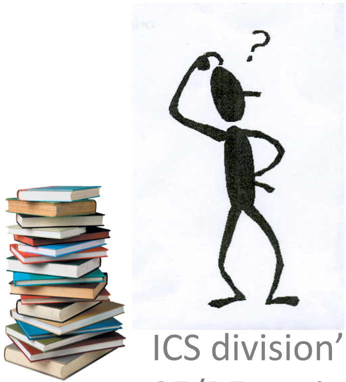
Our case study environment:

The ESS "Integrated Control System" division (ICS)

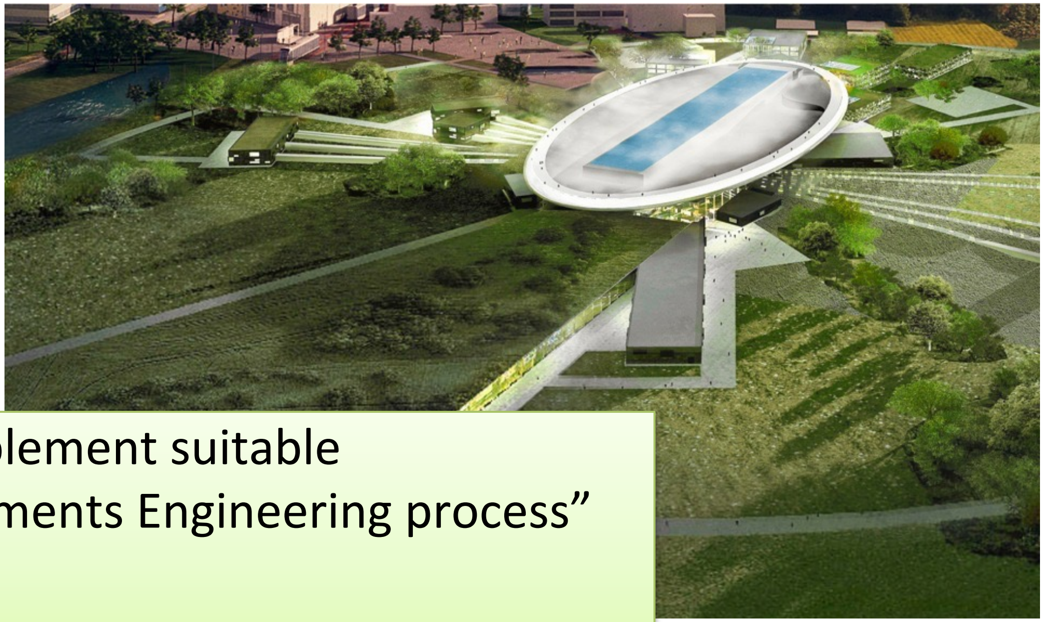
- designs, builds and integrates the largest part of the controls and computing systems of the ESS,
- approx. 40-80 people.

→ ICS needs to implement *Requirements Engineering (RE)*.

The problem at hand:



ICS division's
SE/RE engineer



Task: Implement suitable "Requirements Engineering process" for ICS!

What are the expectations towards our "implemented RE process"?
How do we know, we're implementing the "right" RE?
How are obstructions obstructing our RE implementation efforts?
How do we organize our "process implementation" efforts?

Our INCOSE paper

- A characterization of RE in our domain
  - relation to Project Management
- Implementation approach
  - technical/analytical aspects
  - managerial aspects
- RE implementation at ICS division
- Case study and approach evaluation
- Conclusions
- Questions

Recap
Characteristics of RE in our domain

- Novel technical concepts and architectures,
  - exploratory style of design and development
  - high degree of technical uncertainties,
- Prototypical character throughout the facility's lifetime
  - changing research demands,
  - technological progress, performance upgrades,
- Heterogeneous professional backgrounds
  - different areas in natural sciences, engineering, etc.,
  - different cultures, generations, academic/industry backgrounds,

Recap
Challenges for RE process implementation

- ESS is a greenfield site.
  - organisation is built in parallel,
  - no commonly shared traditions, terminologies, concepts, processes to build on,
- accommodate different engineering approaches
  - ‘typical’ control systems: V-model, ISO 15288 processes
  - safety-critical systems: IEC 61508, IEC 61511
  - software development: Agile techniques (Scrum)
- internationally distributed design and production
- accommodate plant and product development

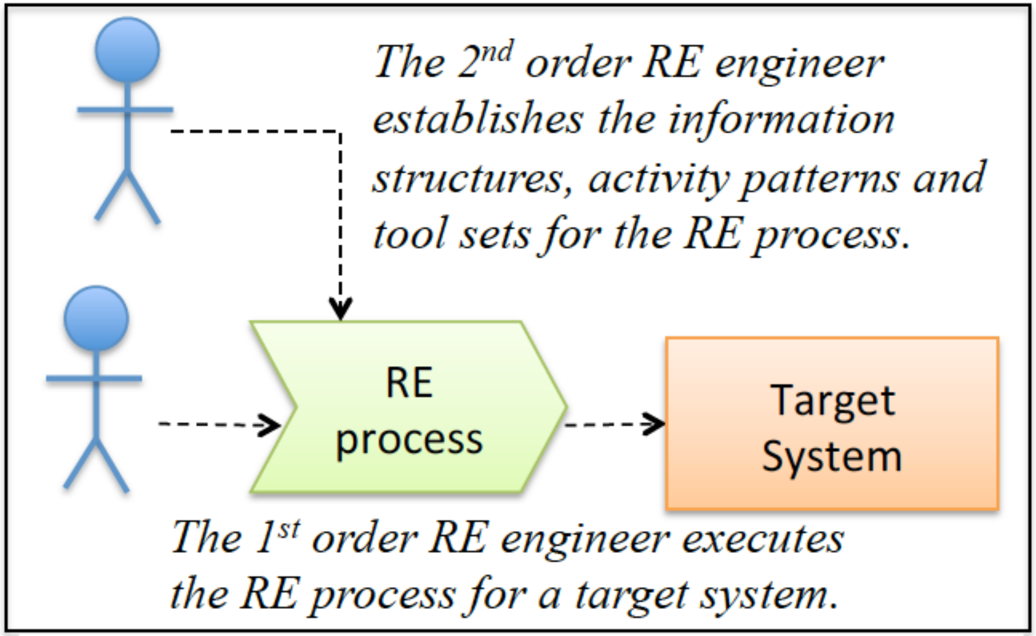
We distinguish between "1st order" and "2nd order" Requirements Engineering

1st order RE: engineering a *system:*

- analysing a system,
- specifying its requirements,
- hosting req's in RE tools, etc.

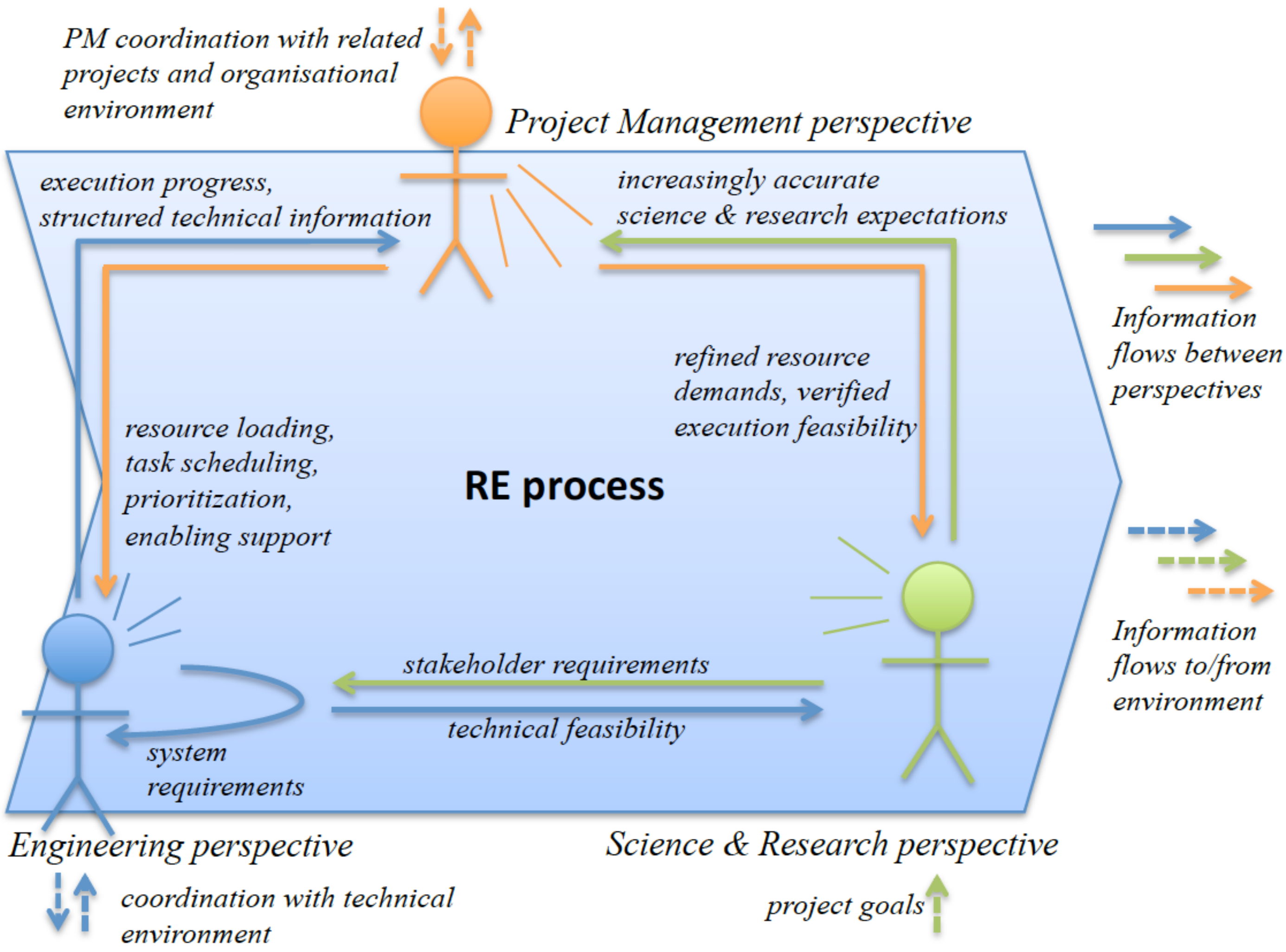
2nd order RE: engineering the *engineering:*

- defining and realising the means by which an organisation performs 1st order RE tasks.

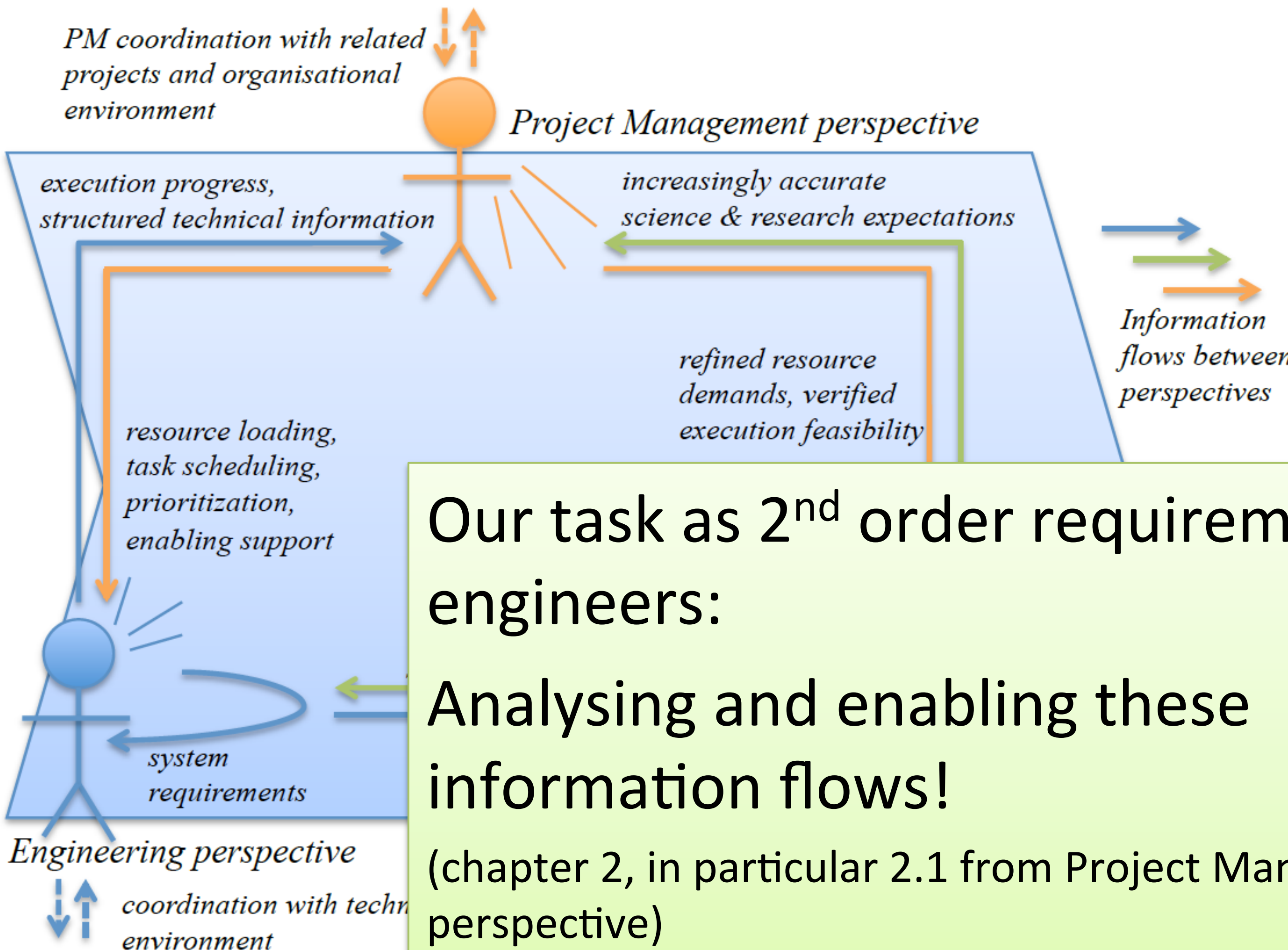


...in practice, often performed by the same persons.

Understanding the RE process in our domain



Understanding the RE process in our domain



Our task as 2nd order requirements engineers:

Analysing and enabling these information flows!

(chapter 2, in particular 2.1 from Project Management perspective)

The Project Management perspective on RE

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The RE process enables Project Management

- to have visibility of technical concerns,
- to separate technical concerns from specifically managerial concerns (deliverables, resource loading, task scheduling),
- identify/mitigate project execution risks (e.g. by initiating prototyping, evaluation studies),
- establish and support appropriate roles,
- establish means for communication flow, (venues, WGs),
- project execution improvement process,
- address uncertainty problem in research engineering,
- to link a project into the other projects,
  - plant system project to technology development project,
  - global project integration into larger environment.

Implementing the "right" RE

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There are many RE flavours...

- How do we know what is suitable for us, - what is not?
- How do we analyse emerging problems?

Encountered problem areas at ESS:

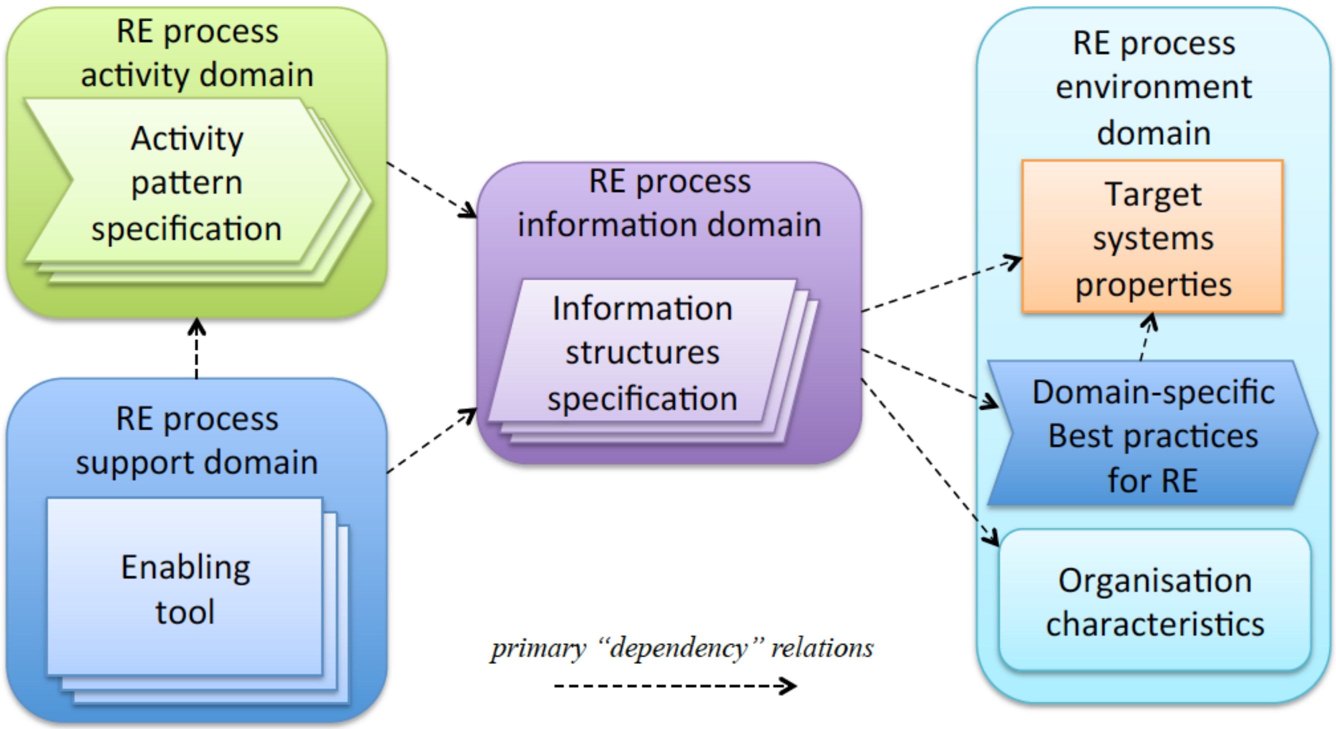
- overall structuring of requirements,
- RE terminology,
- RE formal conventions (template formats),
- RE database tool usage conventions.

Relate to ESS characteristics: young organisation, diverse staff backgrounds, diverse engineering disciplines (SW, safety-critical systems, plant/product development, ...)

How can we analyse this, and find suitable answers?

→ major practical RE implementation problem

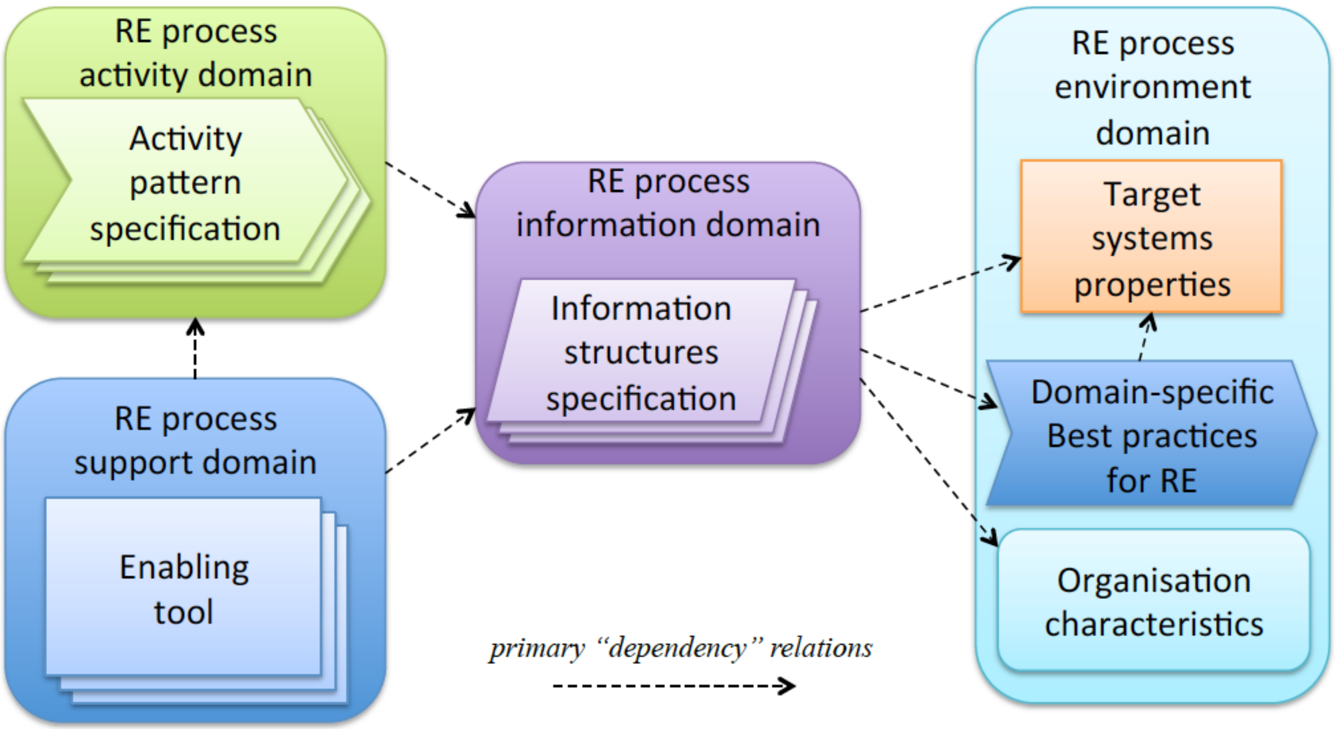
We describe 2nd order
RE Implementation domains



- structure our 2nd order RE efforts
- understand the obstructions

Understanding the …

RE process environment domain



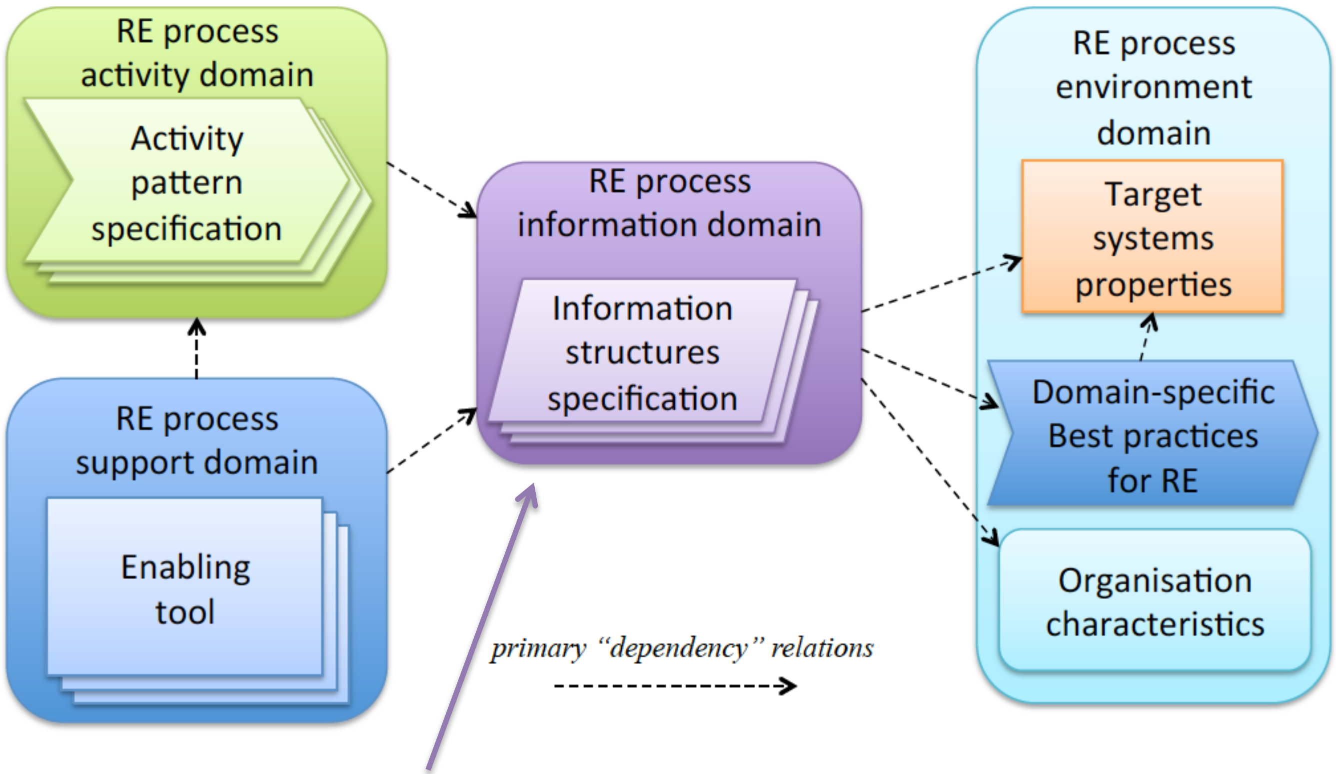
- *technical information needed*

- *IEC 61508*
- *V-model*
- *Agile*

- *ESS green- field org.*
- *staff composition*

Understanding the …

RE process information domain

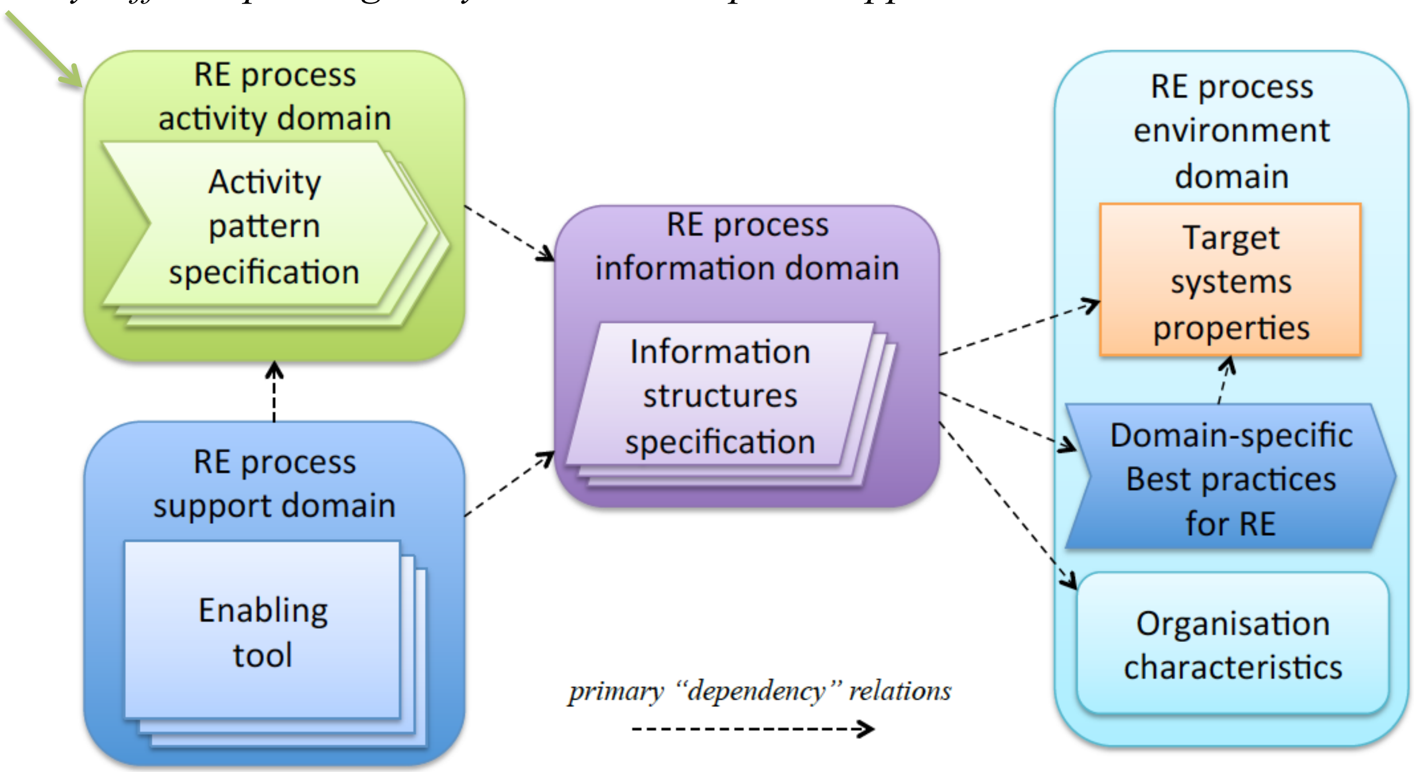


- *technical viewpoints*
- *standardised, abstract information patterns*
  - *e.g. formal req. patterns, template content structures,*
- *overall information hierarchies, breakdowns*

Understanding the …
RE process <u>activity</u> domain

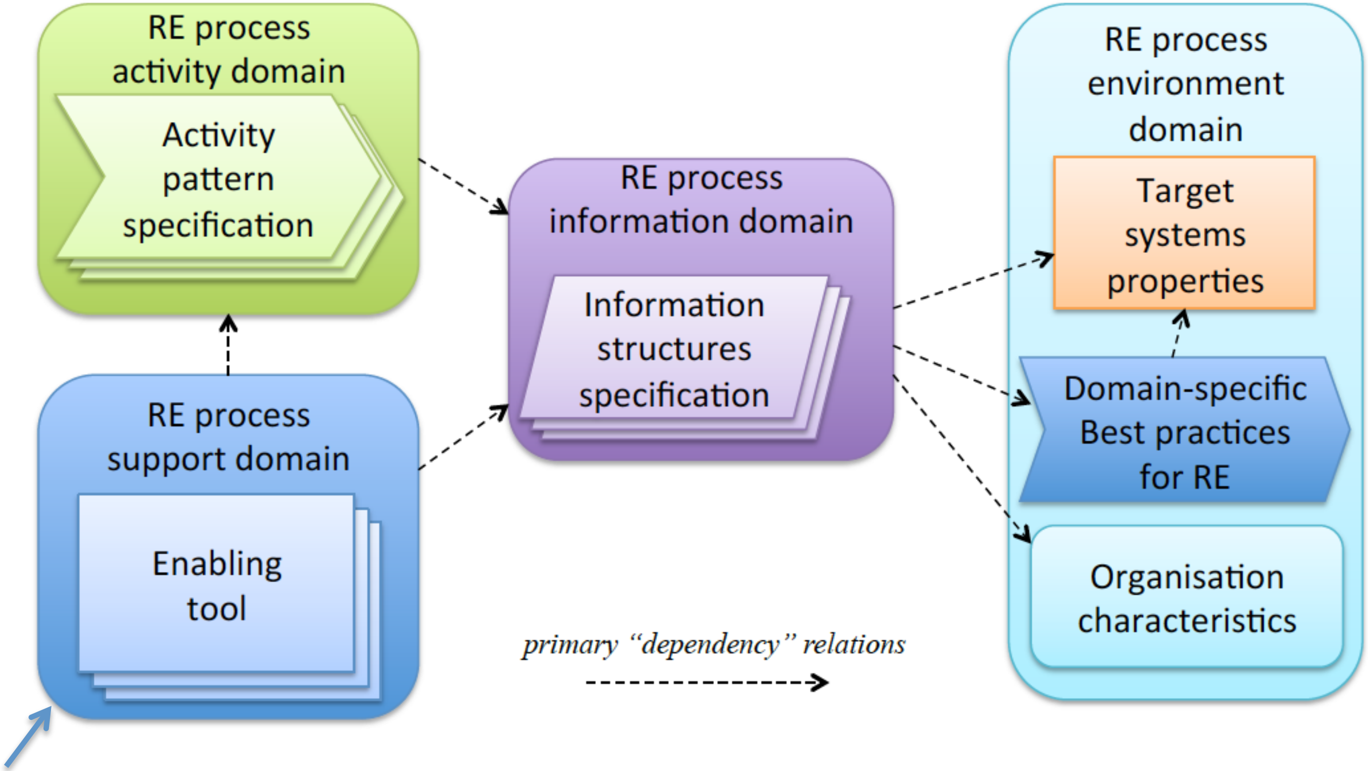
Production of RE information, e.g.
- *analysis techniques,*
- *elicitation techniques,*
- *baseline approval procedures, …*

➢ *may differ depending on system or development approaches*



Understanding the …

RE process support domain



- *provision of word processor templates*
- *provision of database tools*
- *style guides*
- *training*

Practical management of 2nd order RE efforts – iteration pattern

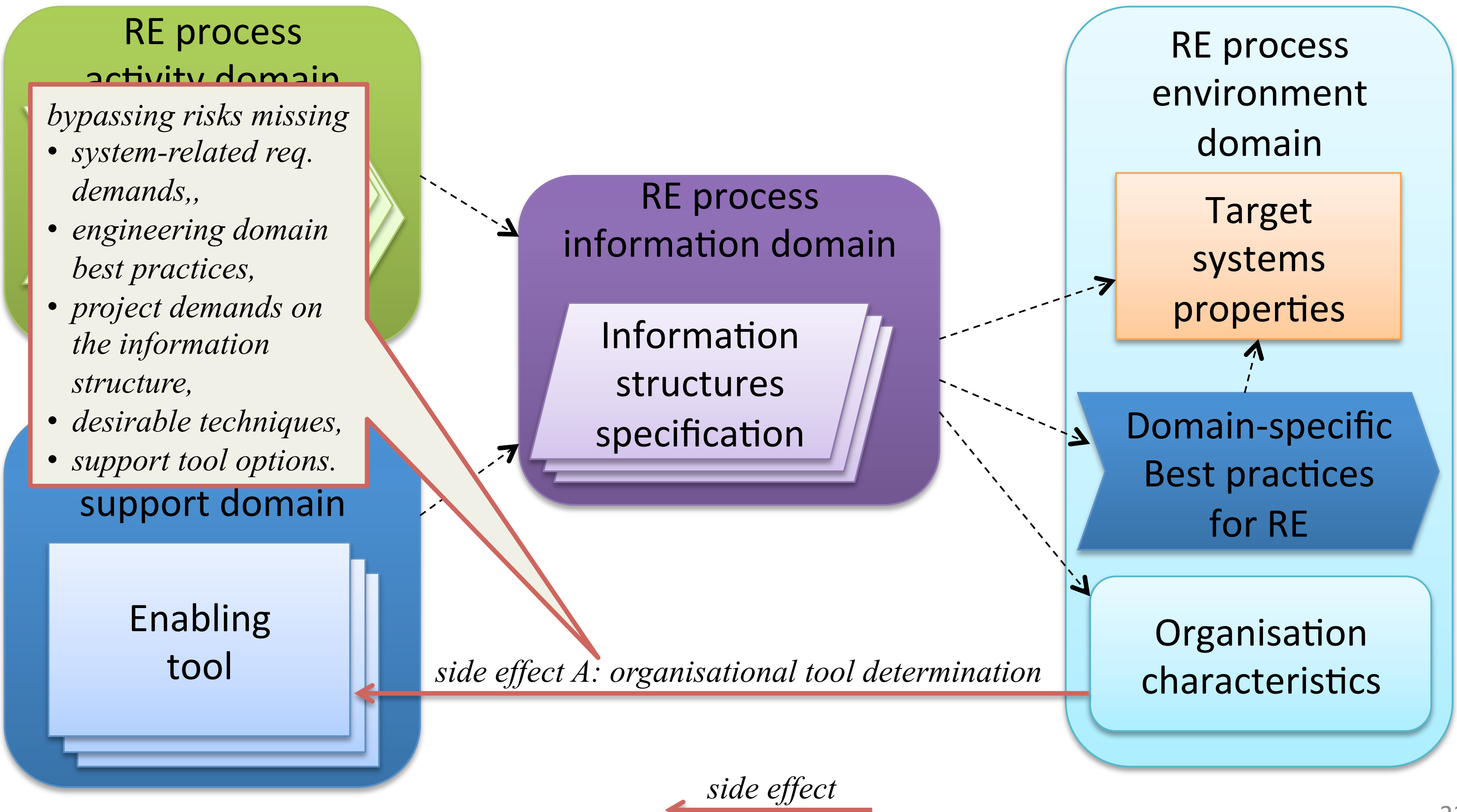
Iteration pattern following the dependency chain as outlined:

Goal oriented process implementation

- analyse various aspects of environment domain,
  - derive what RE outputs (information) will be needed
    - derive, based on the above, suitable activity patterns (processes, procedures, workflows),
      - derive, based on the above, suitable enablers (databases tools, training material, text processor templates, etc.)

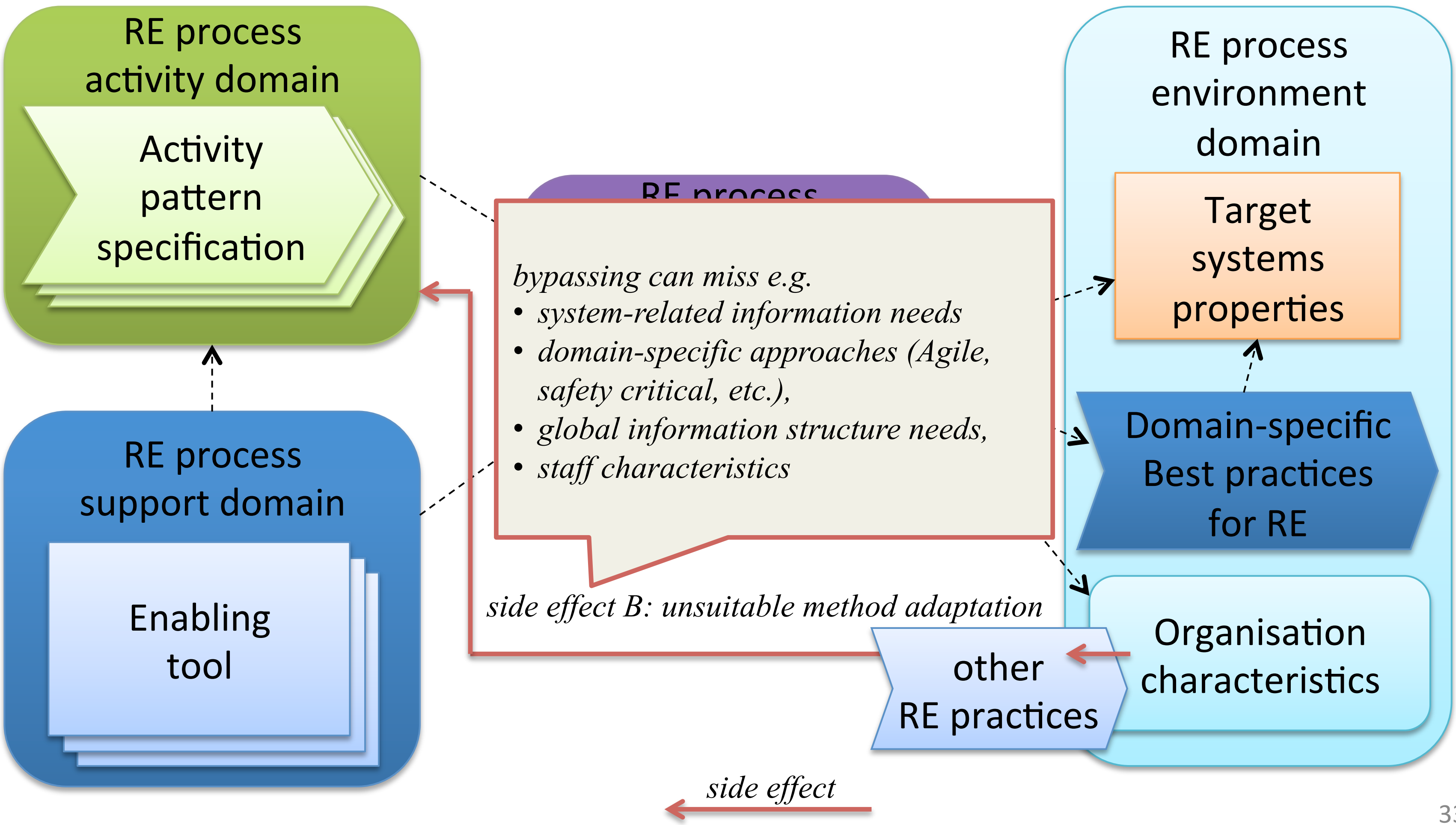
In our paper, chapter 3.1 and 3.2.

Understanding RE implementation problems as ...
Side effects



Understanding RE implementation problems as ...

Side effects



Side effects in practice

Side effects as outlined

- can happen,
- can be difficult to identify,
- can be difficult to agree on with others,
- can be difficult to resolve due to consolidation cost.

→ major practical RE, SE problem for new organisation.

In our paper, chapter 3.1.

Practical management of 2nd order RE efforts – Agile methods

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- 2nd order RE activities need to be managed.
- Product view on RE process for our division: treating it as an "information-processing machine".
  - apply life cycle management to 2nd order RE process.

RE implementation in our domain/ our case study is

- is explorative,
- is incremental (we need some things now, others later),
- requires continuous learning from practice,
- needs to react to the changing organisation.

➢ Agile methods seem most suitable to managing RE implementation.

Practical management of 2nd order RE efforts – Agile methods

Metaphor: “programming an organisation”, oriented at Scrum.

- An RE process implementation *backlog* (tasks) defines 2nd order RE implementation efforts, helps planning.
- The *backlog* makes RE implementation efforts transparent to process users and PM.
- *Sprints* encourage early delivery and incremental improvements of “deliverable components” (e.g. template, database configuration, written guides, etc.)
- Early delivery and *demonstrations* enables early verification and validation (do our ideas actually work for our engineers?)
- *Retrospectives* on improving the process implementation.

In our paper, chapter 3.2.

Case study evaluation
Controls division at ESS

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A bit more detail on our RE process implementation ...

- environment characterization: ESS controls
- information domain: relevant technical viewpoints, template structure for requirements spec's
- activity domain: different engineering approaches
- support domain: enabling RE tools, training support, initiation of RE process execution
- side effects observed
  - external/internal,
  - under-/over-determination of RE concepts.

In our paper, chapter 4.

Evaluation and contribution

- Characterisation of RE implementation in our domain
  - understanding expectations and related information flows
- Implementation approach
  - goal oriented, oriented at inherent domain dependencies
  - understanding obstructions to RE implementation
- Implementation management
  - Agile oriented

- Still “early” in the ESS project (full operation: 2025...)
  - approach needs further refinement and long-term evaluation

Conclusions

- Practical process implementation seems generally not well described, given the problem it constitutes.
  - Tailoring of processes: how?
  - Identifying and solving obstructions.
- Approach transferable from RE implementation to other processes?
- Knowledge base for process implementation and tailoring would be helpful
  - showing domain-specific but transferable aspects
  - explaining domain-typical problems

Thank you for your attention! Questions?

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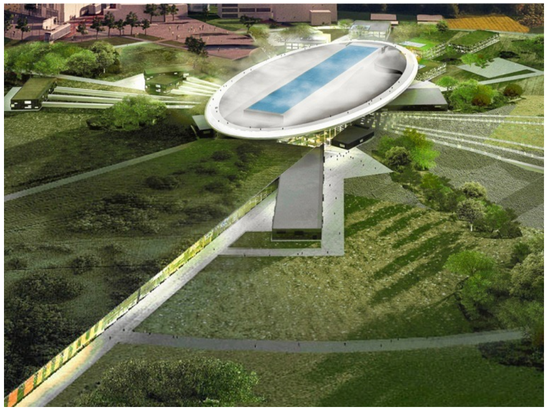
European Spallation Source ESS



- Characterisation of RE implementation in our domain
  - understanding expectations and related information flows
- Implementation approach
  - goal oriented, oriented at inherent domain dependencies
  - understanding obstructions to RE implementation: side effects
- Implementation management
  - Agile oriented

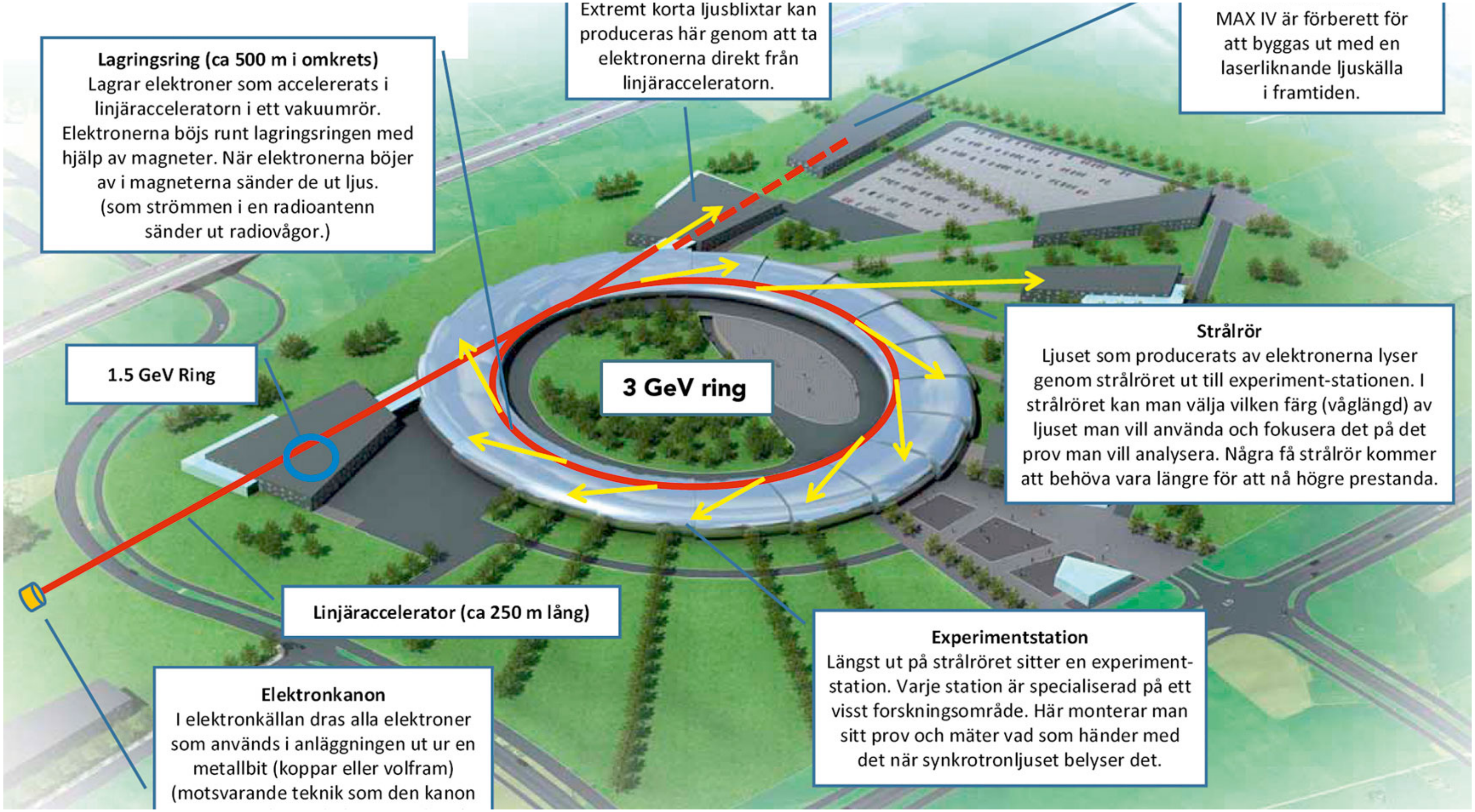
References

- European XFEL: http://photon-science.desy.de/sites/site_photonscience/content/e58/e187156/e201405/e201809/XFEL_Orthophoto-2012_diagonal_eng.jpg
- LHC: http://www.ee.washington.edu/faculty/hauck/LargeHadronCollider/

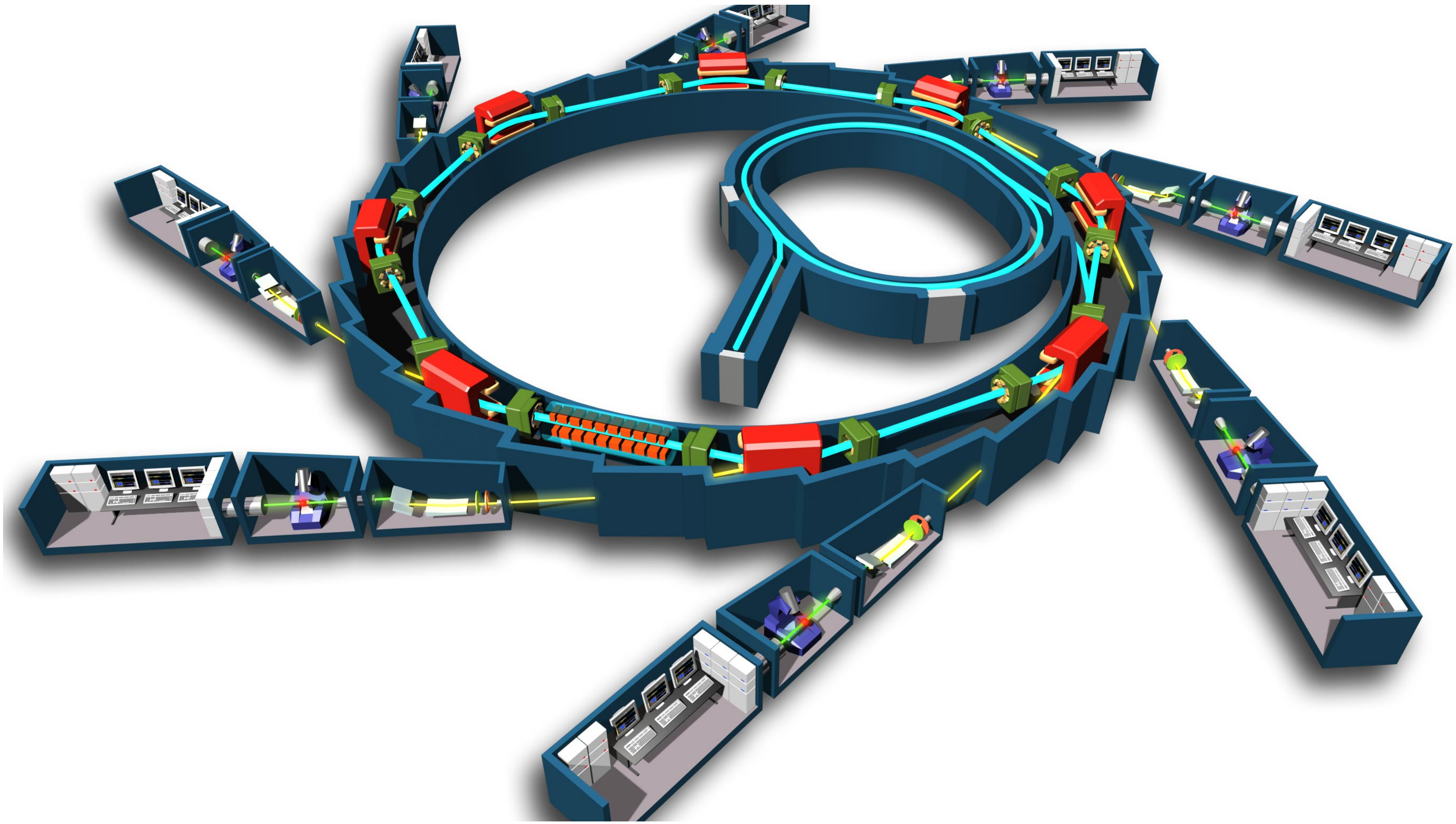
Back-up slides

- MAX IV overview
- Soleil

Schematic
MAX IV



Schematic Synchrotron Light Source Soleil



https://en.wikipedia.org/wiki/Synchrotron_light_source