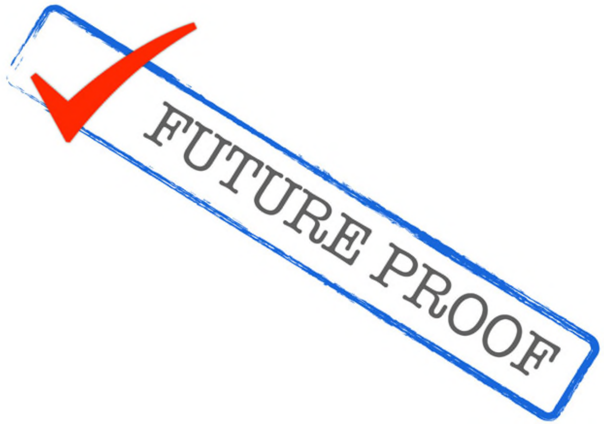


https://static1.squarespace.com

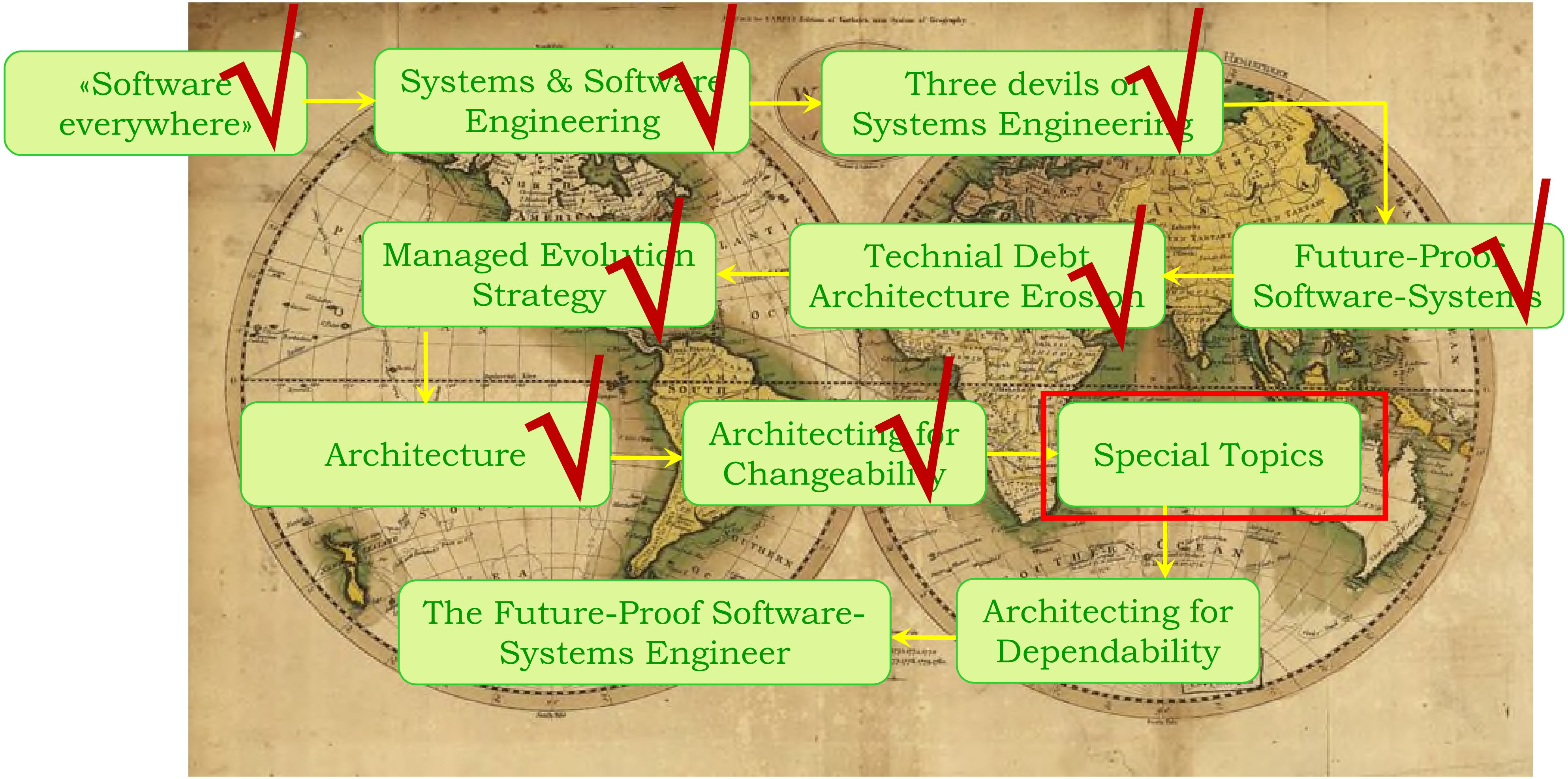
Future-Proof Software-Systems (FPSS)

Part 3C: Special Topics (1)

Lecture WS 2017/18: Prof. Dr. Frank J. Furrer

Version 1.0

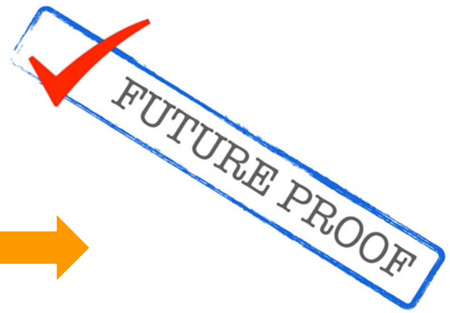
Our journey:


«Software everywhere»
Systems & Software Engineering
Three devils of Systems Engineering
Future-Proof Software-Systems
Technial Debt Architecture Erosion
Managed Evolution Strategy
Architecture
Architecting for Changeability
Special Topics
Architecting for Dependability
The Future-Proof Software-Systems Engineer

Special Topics = Specific IT-Architecture Areas related to IT-Systems

Part 3C

- Cyber-Physical Systems (CPS)
- Systems-of-Systems (SoS)
- Cyber-Physical Systems-of-Systems (CPSoS)
- Cloud Computing
- Microservices
- Agile Manifesto and Future-Proof Software-Systems ?
- Domain Software Engineering
- Legacy System Migration/Modernization
- Software Product Lines



Future-Proof Software-Systems

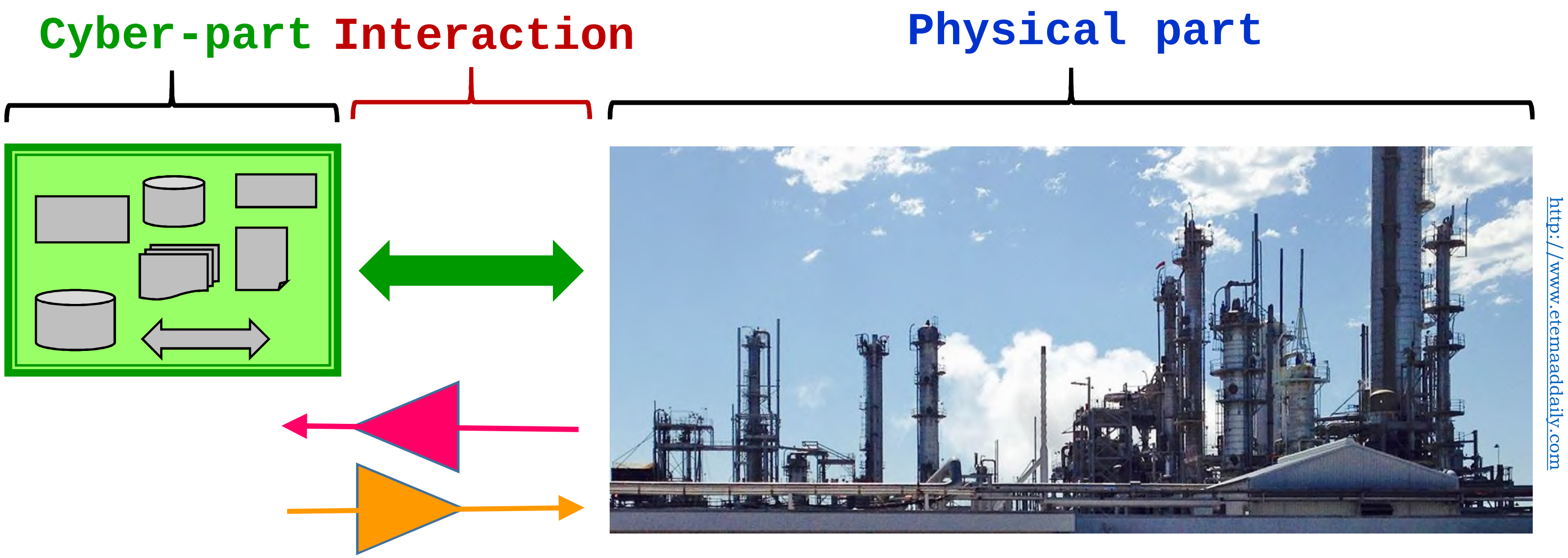
Cyber-Physical Systems (CPS)

Cyber-Physical System (CPS)

DEFINITIONS

A **cyber-physical system** (CPS) consists of a computing device interacting with the physical world in a feedback loop

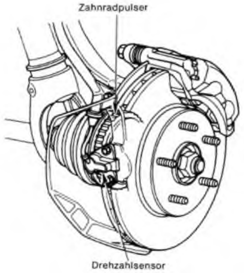
Rajeev Alur, 2015]



Sensors: Read plant information

Actuators: Control plant

CPS-Example: **ESC**



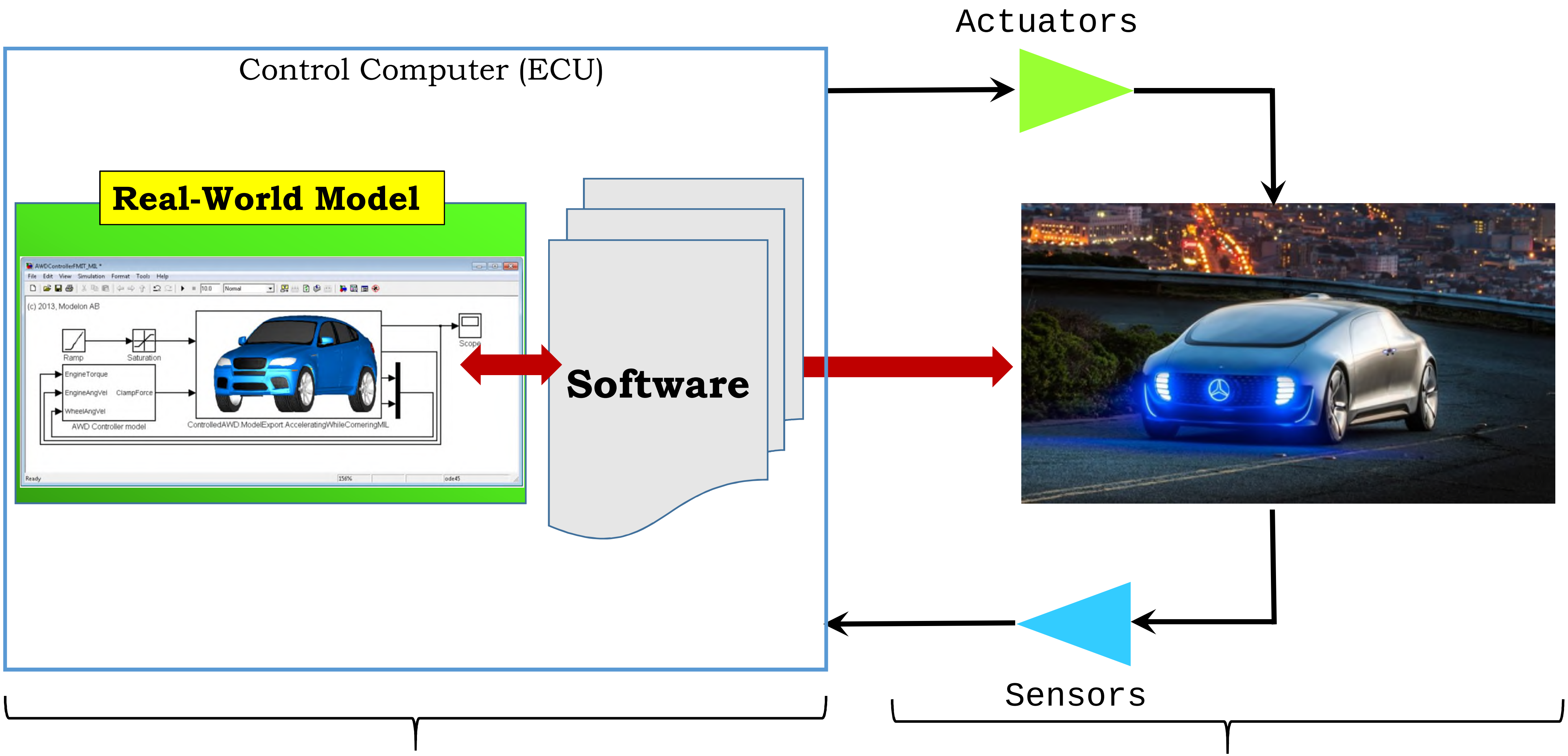
http://www.polizeiticker.ch

ECU (SW)

Kowledge Base

Feedback Loop

http://www.modelon.com



http://cdn1.alphr.com

Cyber-Part **Physical-Part**

https://www.siemens.com

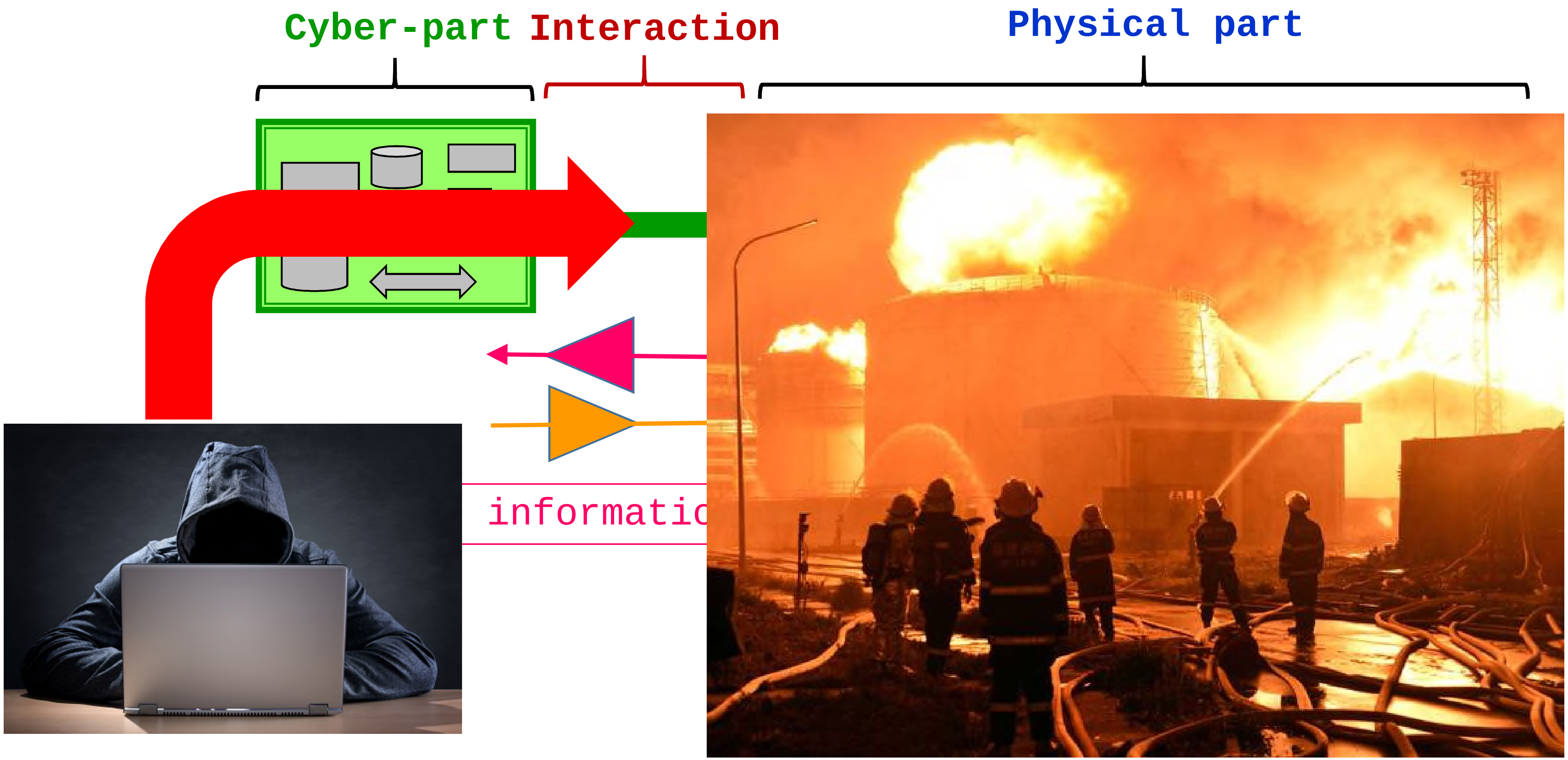
Cyber-physical systems control more and more of our physical devices (Cars, planes, trains, …)

https://tr3.cbsistatic.com

$\Rightarrow$ **Dependability** becomes the key issue

Dependable **architecture** (resilience)	Dependable **software** (trustworthiness)	Dependable **implementation** (correctness)

Risk: Cyber-Physical Attacks



Trustworthy Cyber Physical Systems

https://www.jigsaw.ie

http://images.dailykos.com

Trustworthiness of a system is the *expectation* that the system will do what it should do, and not do what it should not do, both in expected and in unexpected conditions

http://www.anzor.com.au

Dependability

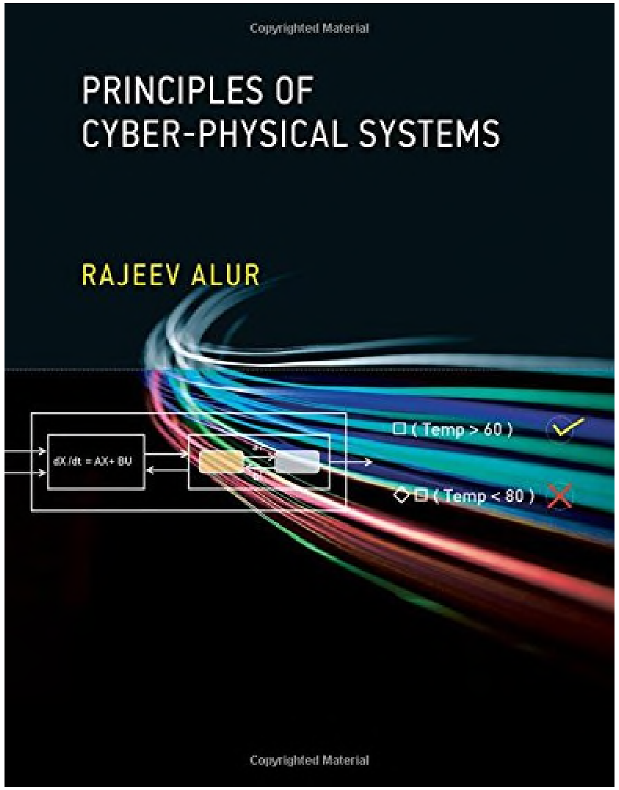
Dependability Architecture Principles (Part 4)

Recommendations

Cyber-Physical Systems (CPS)

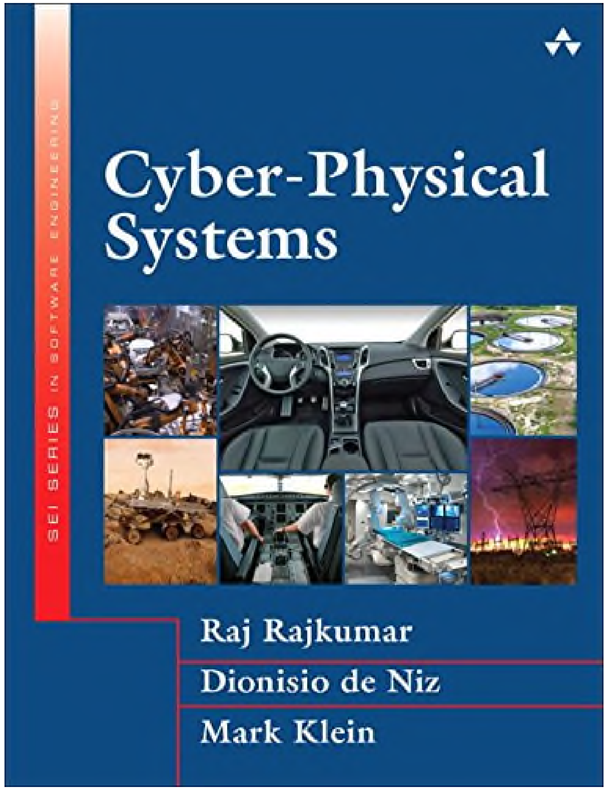
1. *Dependability properties* (safety, security, …) always superse functionality requirements – in specifications, architecture, design, implementation, and operation
2. Implement *monitoring capabilities* to predict or detect abnormal or dangerous behaviour

Textbook



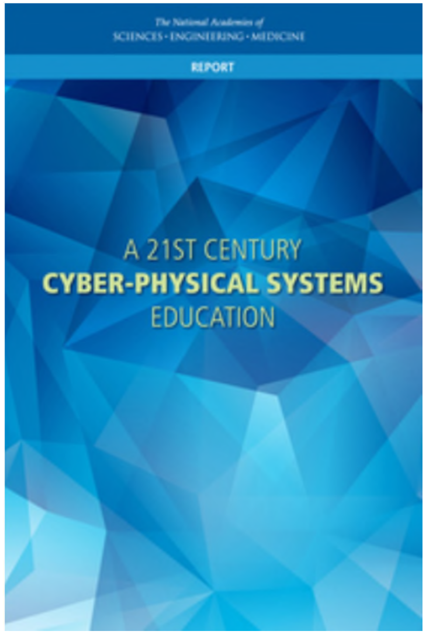
Rajeev Alur:
Principles of Cyber-Physical Systems
MIT Press, Cambridge, USA, 2015. ISBN 978-0-262-02911-7

Textbook



Raj Rajkumar, Dionisio De Niz, Mark Klein:
Cyber-Physical Systems
Addison Wesley Inc., USA, 2016
ISBN 978-0-321-92696-8

Textbook



USA National Academies of Sciences, Engineering, and Medicine:
21st Century Cyber-Physical Systems Education
2016, ISBN 978-0-309-45163-5
Downloadable from :
https://www.nap.edu/download/23686

Systems-of-Systems (SoS)

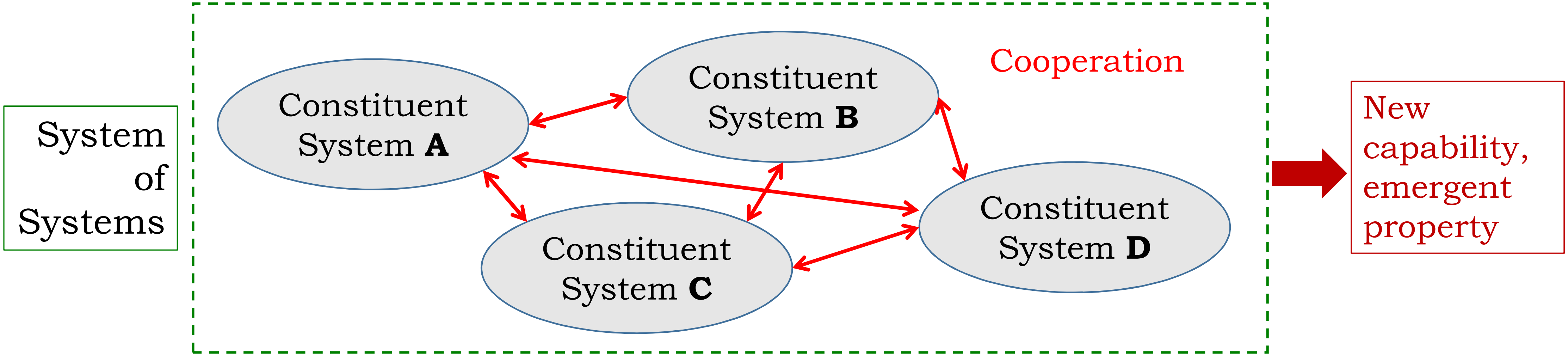
System-of-Systems (SoS)

A **system of systems (SoS)** brings together a set of *cooperating systems* for a task that none of the systems can accomplish on its own (= emergent property).

Each constituent system keeps its own management, goals, and resources while coordinating within the SoS and adapting to meet SoS goals.

ISO/IEC/IEEE 15288 Annex G

DEFINITIONS



Example 1 for emerging properties: „flying“

http://www.mskgmbh.com

Constituent systems (CS) of an aircraft:

- engines
- body
- wings
- cockpit
- etc.

… none of the constituent systems is able to fly !

Assemble the essential constituent systems:

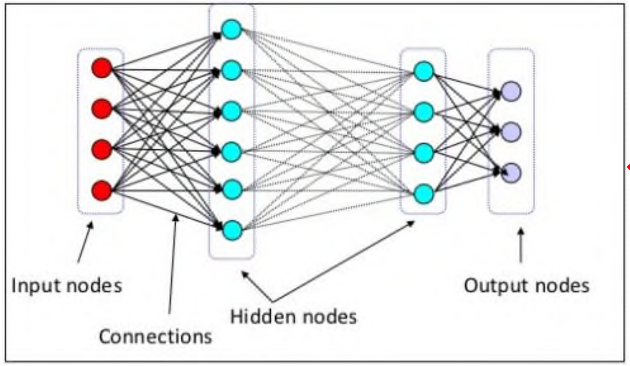
Emerging property: the assembly (= airplane) is able to **fly** !

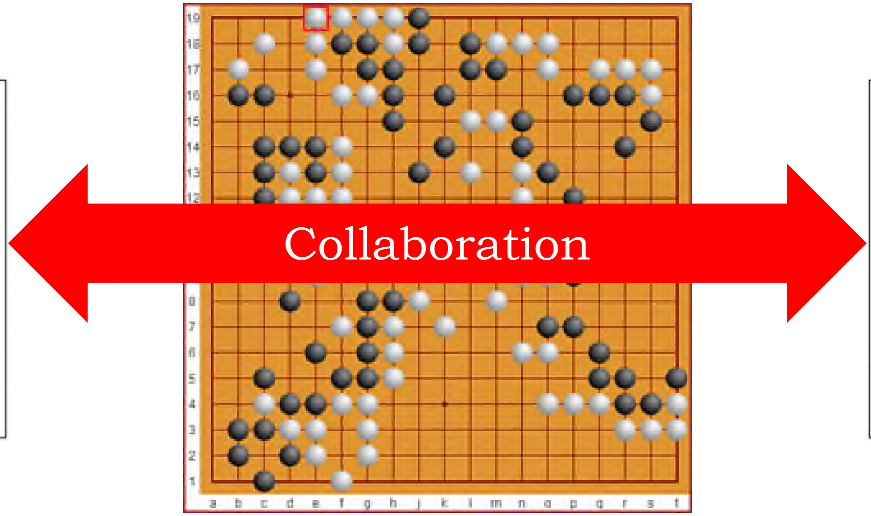
http://en.wikipedia.org/wiki/Airbus_A320_family

Example 2 for emerging properties: „AlphaGo Zero“

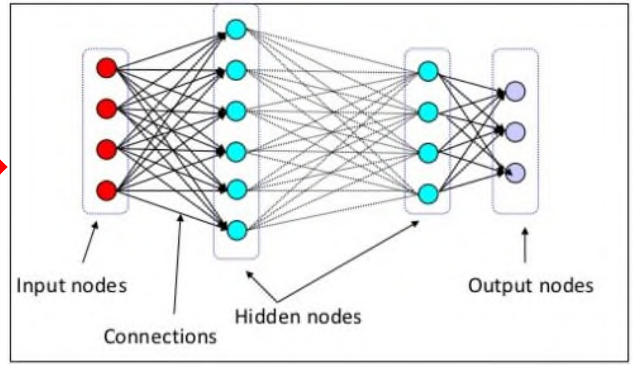
AlphaGo's team published an article in the journal Nature on 19 October 2017, introducing **AlphaGo Zero**, a version created without using data from human games, and stronger than any previous version

Constituent System **A**





Constituent System **B**



AlphaGo Zero is so powerful because it is "no longer constrained by the limits of human knowledge“ [Demis Hassabis, 2017]

Example 3 for emerging properties: „Landing Crash“

http://avioners.net/2011/03/airbus-a319-approach-to-landing.html

Constituent systems:

- Airplane (DC-8)
- Airport (Runway)

October 8, 1979: Swiss Air Flight 316 overran the Athens runway – 14 deaths

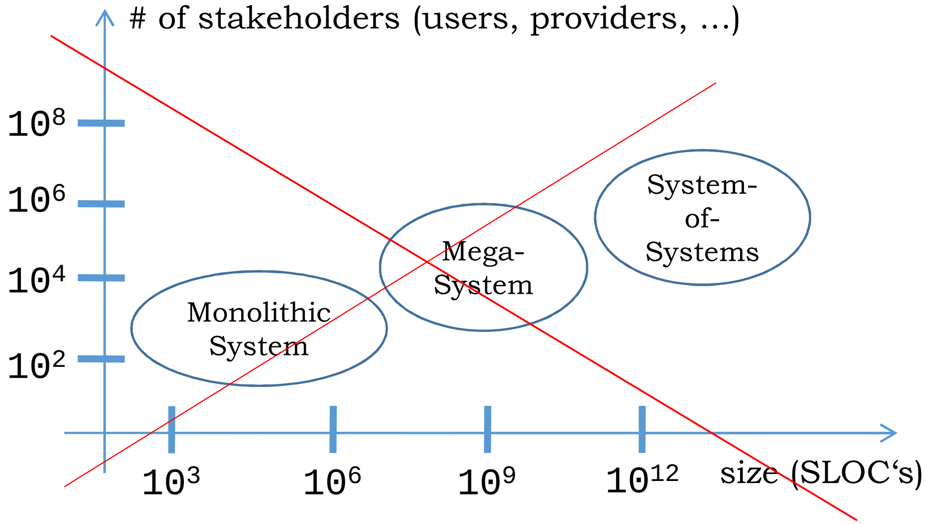
Cause: „Interface“ between the runway and the airplane

- Landing when braking action is less then good
- Crew mistakes

SoS Emergent Behaviour **Classification**

Emergence	Desirable/positive	**Undesirable/negative**
Expected emergent behavior	Reason for building the SoS (**SoS objective**) 	**Mitigate** by appropriate design measures, such as threat/risk analysis and countermeasures 
Unexpected emergent behavior	Sometimes (however, quite rarely) an SoS shows unexpected, **beneficial behaviour** 	<u>Un</u>expected & <u>un</u>desirable negative emergent behavior is one of the **critical risks** of most SoS 

What is a system-of-systems ?



Mark W. Maier:
SoS Criteria

Monolithic systems ⇔ Systems-of-systems:

1. Operational Independence of the Elements
2. Managerial Independence of the Elements
3. Evolutionary Development
4. Emergent Behavior
5. Geographic Distribution

[5 Maier criteria, 1998]

[5 Maier criteria, 1998]

Systems-of-systems characteristics:

1. Operational Independence of the Elements
2. Managerial Independence of the Elements
3. Evolutionary Development
4. Emergent Behaviour
5. Geographic Distribution

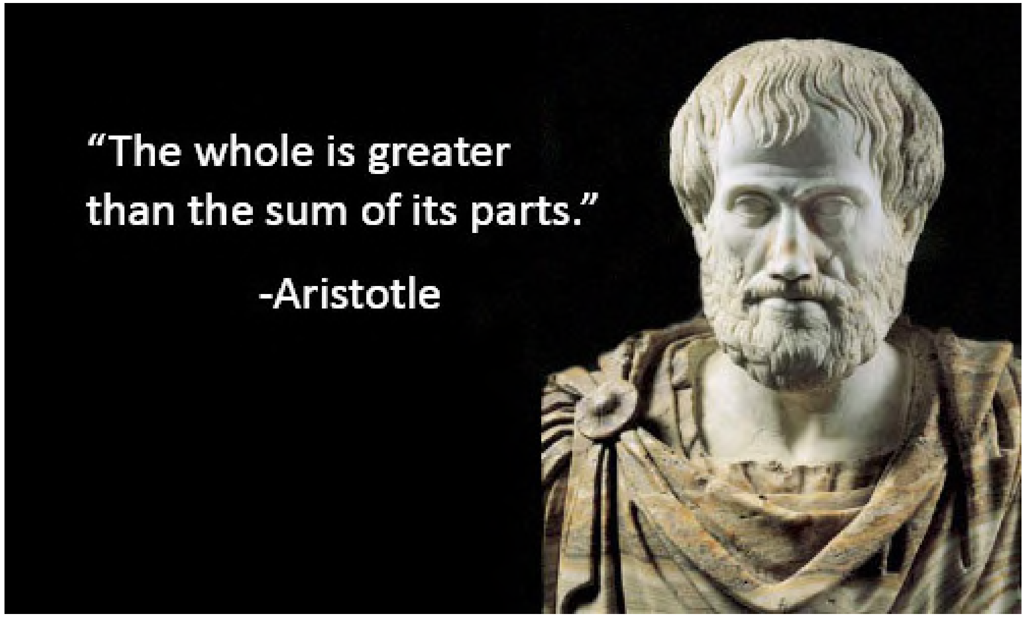
Governance

Total = more than the sum of its parts

Collaboration

Collaboration Contract

- functional
- operational
- commercial
- legal

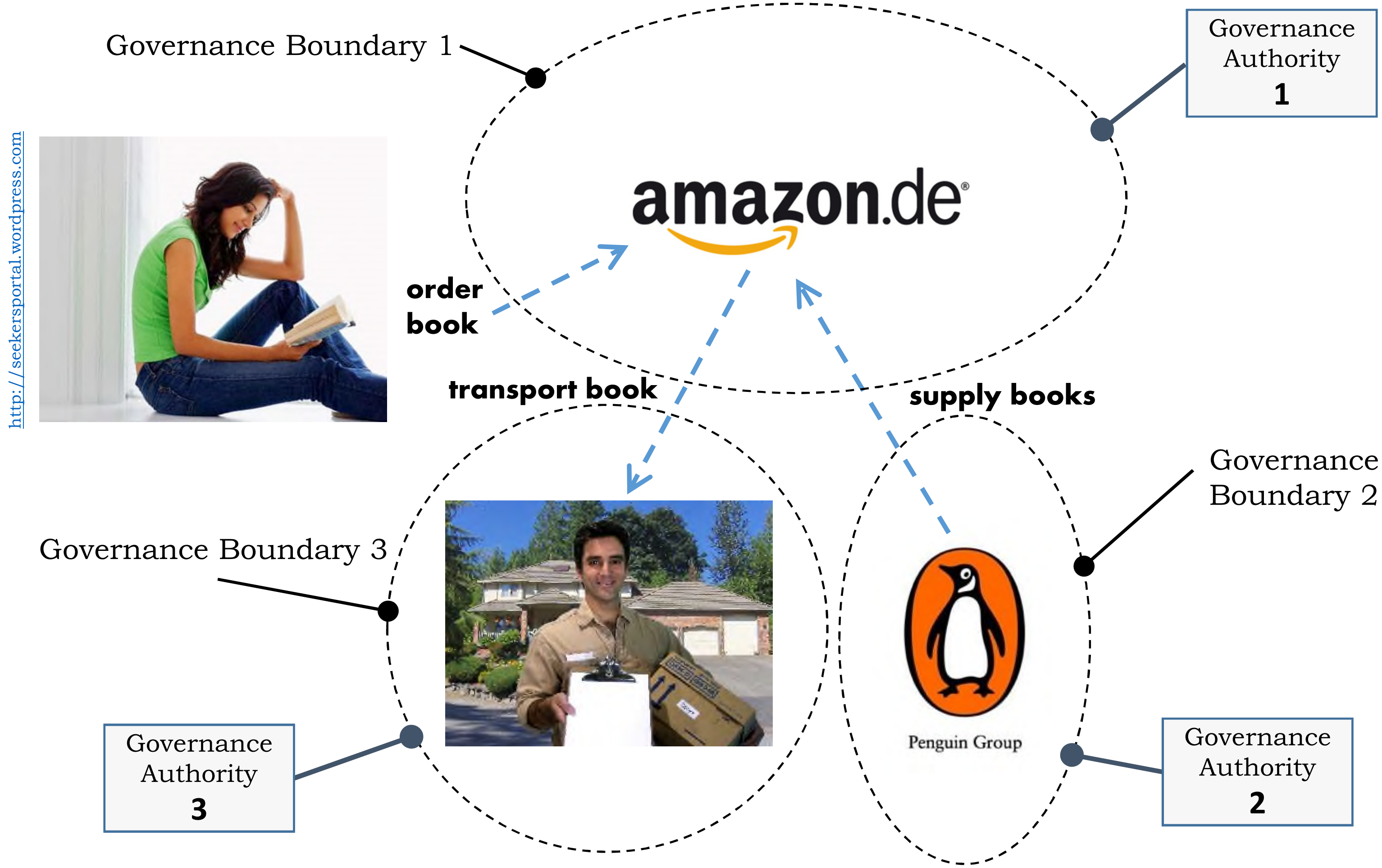


https://i.pinimg.com

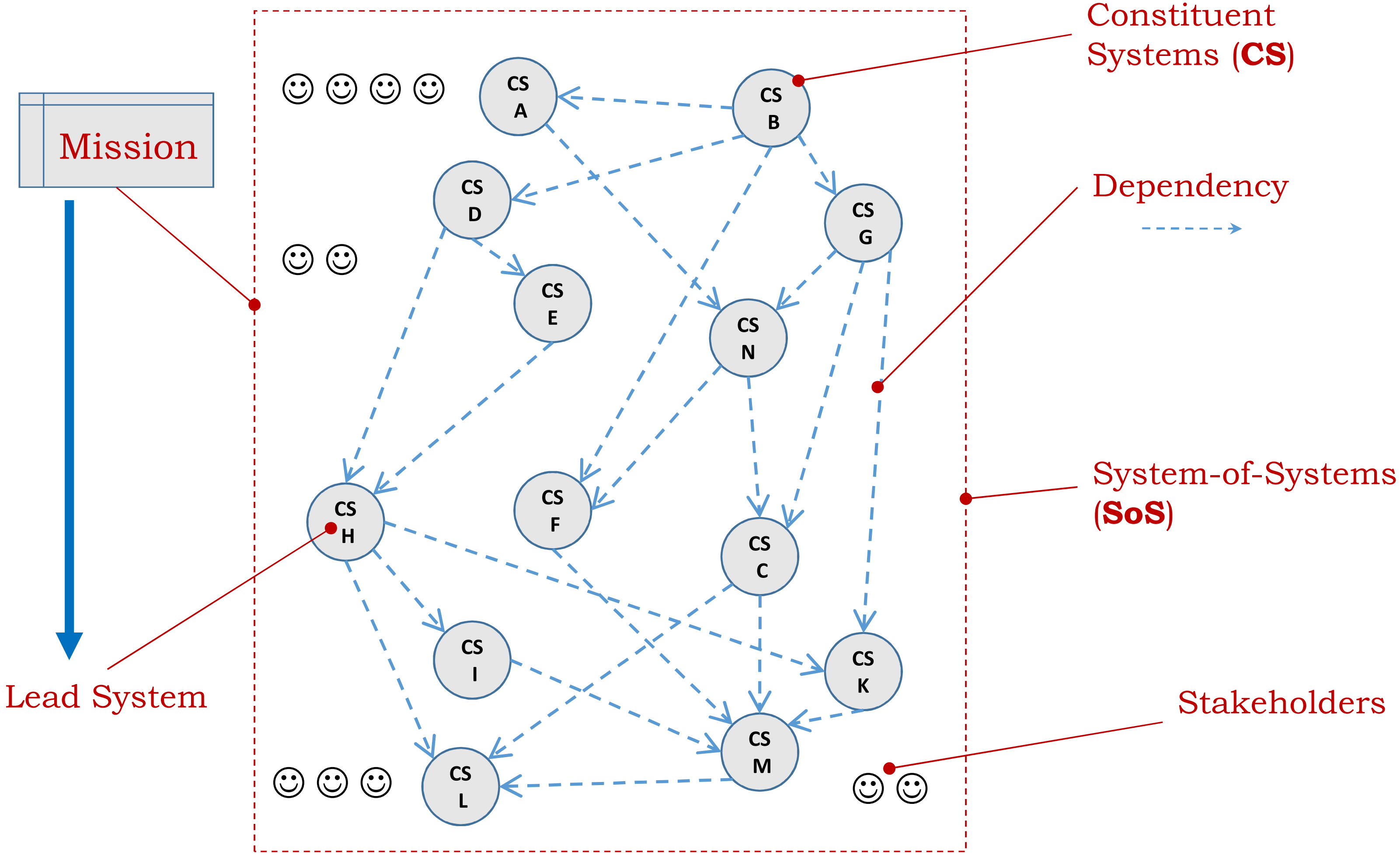
Managerial Independence of the Elements

Governance

SoS Example:
AMAZON
Business Model

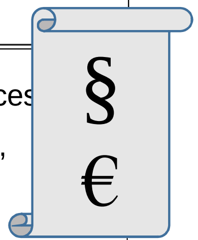


SoS (Systems-of-systems) Terminology

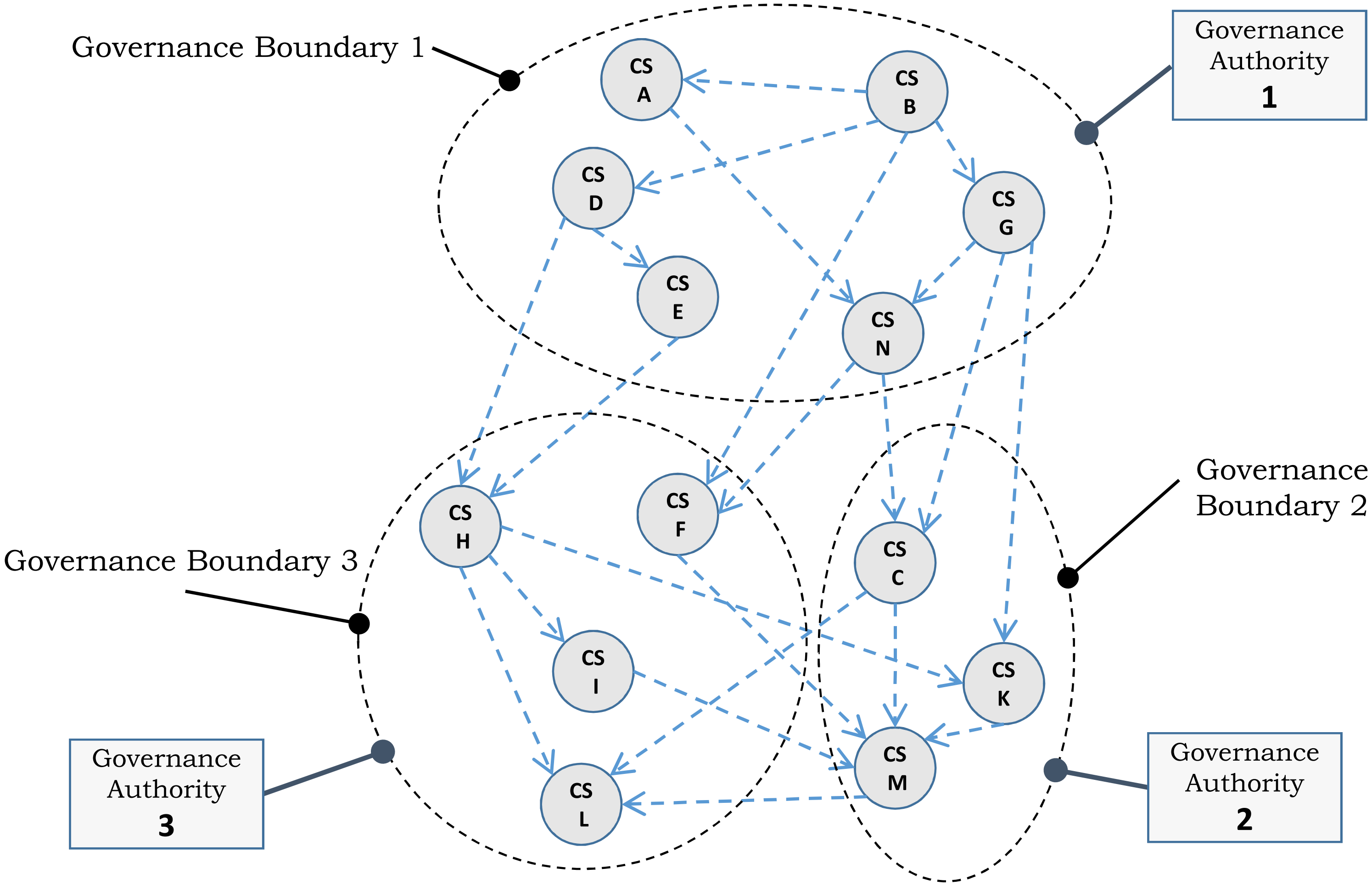


SoS
(Systems-of-systems) Classification

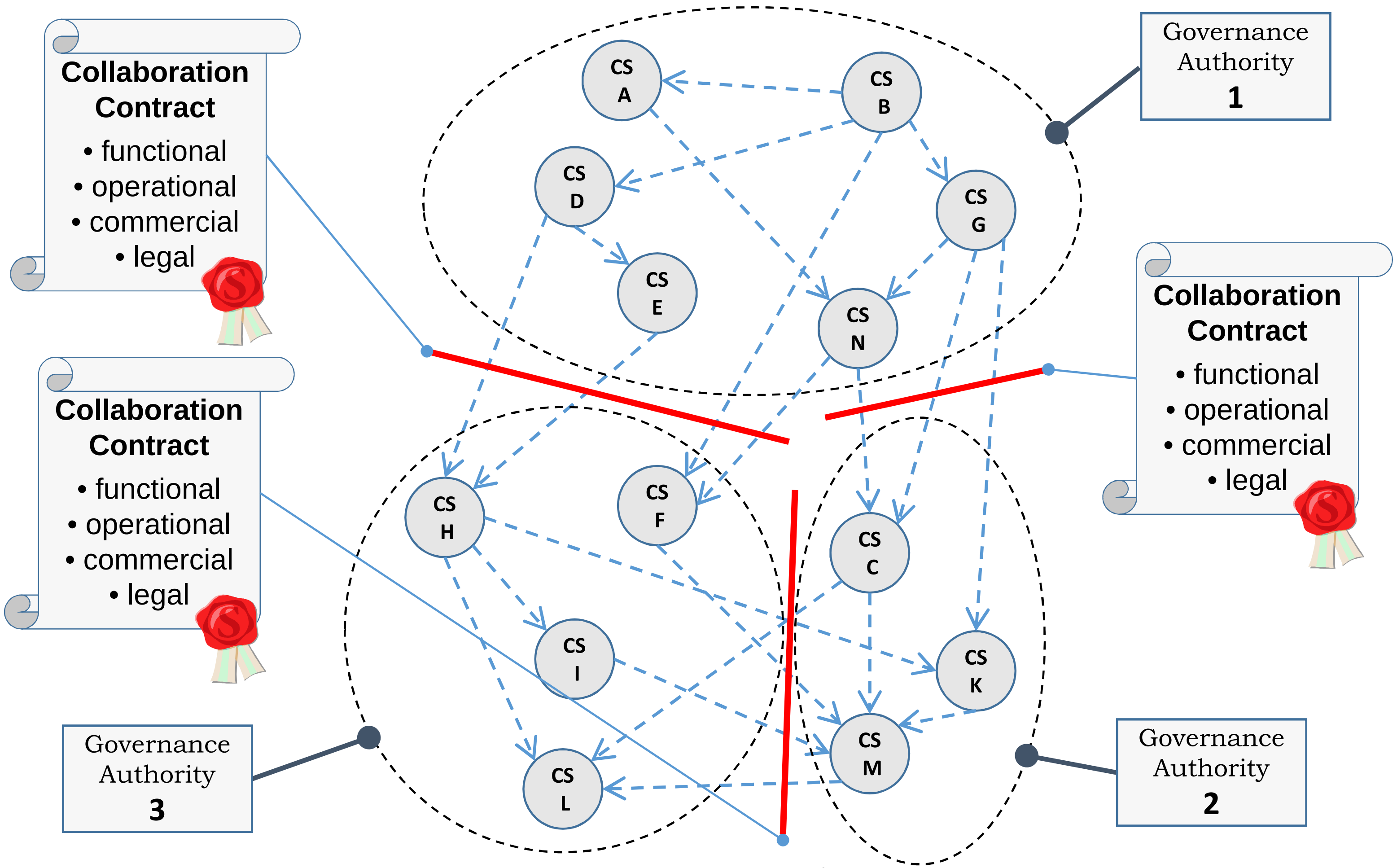
Type of SoS	Description
Directed	Directed SoS are those in which the integrated system-of-systems **is built and managed to fulfill specific purposes**. It is **centrally managed** during long-term operation to continue to fulfill those purposes as well as any new ones the system owners might wish to address. The constituent systems maintain an ability to operate independently, but their normal operational mode is **subordinated to the central managed SoS purpose**
Acknowledged	Acknowledged SoS have recognized objectives, a designated manager, and resources the SoS. However, the **constituent systems retain their independent ownership**, objectives, funding, and development and sustainment approaches. Changes in the systems are **based on collaboration** between the SoS and the systems
Collaborative	In collaborative SoS the **constituent systems interact more or less voluntarily** to fulfill agreed upon central purposes. The central players **collectively decide** how to provide or deny service, thereby providing some means of enforcing and maintaining standards.
Virtual	Virtual SoS **lack a central management authority** and a centrally agreed upon purpose for the system- of-systems. Large-scale behavior emerges – and may be desirable – but this type of SoS must rely upon **relatively invisible mechanisms** to maintain it



Managerial Independence: **Governance**

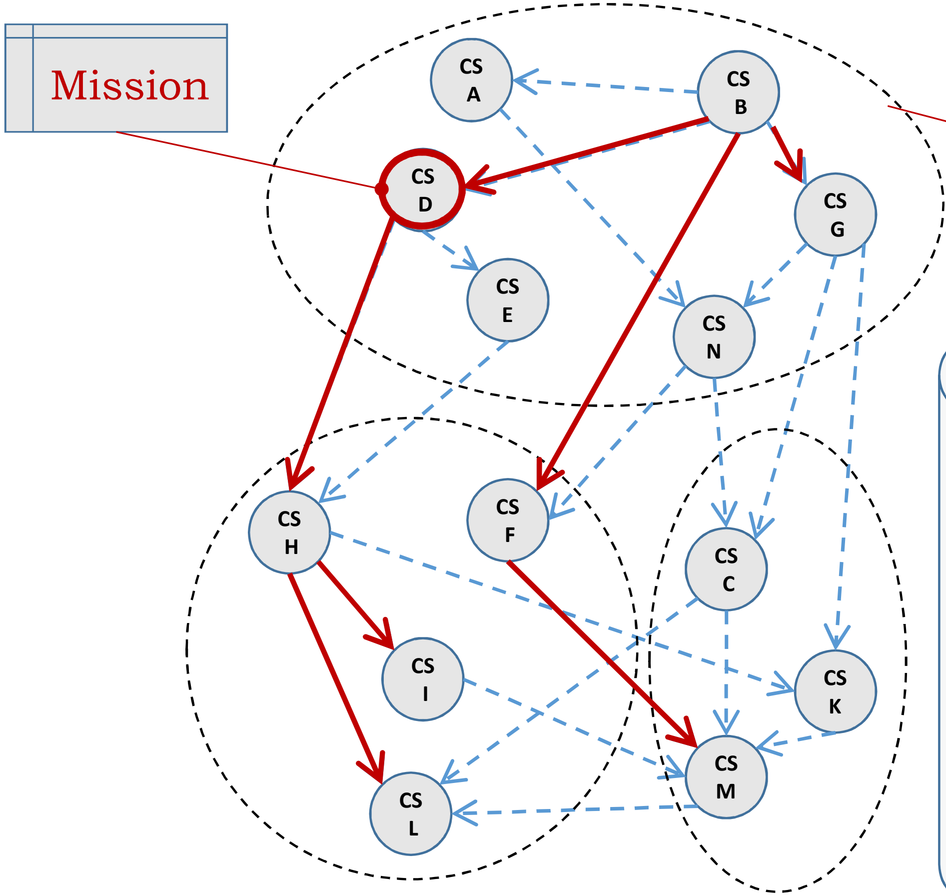


Managerial Independence: **Governance by Contract**



... now we understand SoS's and their challenges

... what does it mean for our future-proof software?



1) Transparent architecture
2) Explicit dependencies
3) Complete contracts
4) Risk mitigation
5) Monitoring and early response

Systems-of-Systems Engineering (**SoSE**)

SoS Architect's Responsibility:

1) Transparent architecture
2) Explicit dependencies
3) Complete contracts
4) Risk mitigation
5) Monitoring and early response

Structure & Behaviour Model

Identify, document and understand all dependencies (i.e. make them explicit, no implicit dependencies!)

Define all dependencies by contracts:
- Functional
- Operational
- Commercial

Identify, assess and mitigate all risks in the SoS in relationship with the SoS mission

Define and implement mechanisms to monitor the correct operation of the SoS and to react early to deviations

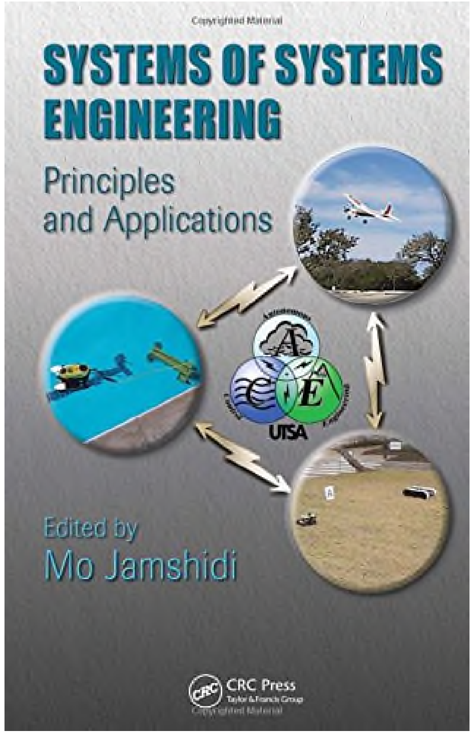
Recommendations

Systems-of-Systems (SoS)

1. Develop and maintain a transparent, complete, up-to-date, well documented architecture for the SoS
2. Fully understand and (formally) specify all dependencies
3. Fully understand and (legally) specify the governance of the SoS
4. Define all dependencies by formal contracts
5. Use effective risk analysis and mitigation for the early detection of operational faults, errors or unwanted emergent behaviour
6. Implement monitoring capabilities to detect unwanted emergent behaviour

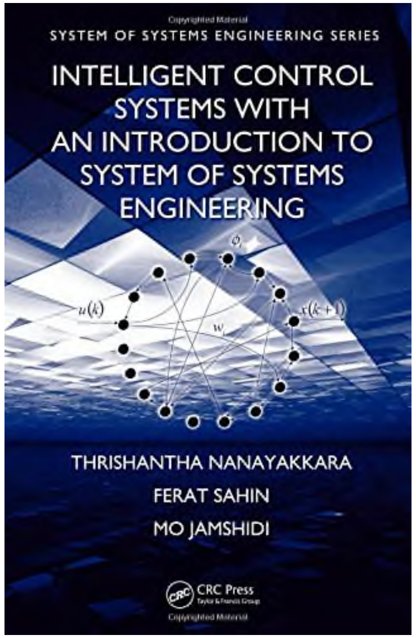
Justification: Due to the fragmented governance/ownership in a system-of-systems, the management, evolution and operation of a SoS are more demanding. Therefore new procedures, engineering processes and operational measures must be used.

Textbook



Mo Jamshidi:
Systems of Systems Engineering – *Principles and Applications*
CRC Press Inc., USA, 2008. ISBN 978-1-420-06588-6

Textbook



Thrishantha Nanayakkara, Ferat Sahin, Mo Jamshidi:
Intelligent Control Systems with an Introduction to Systems of Systems Engineering
CRC Press Inc., USA, 2009. ISBN 978-1-420-07924-1

Cyber-Physical Systems-of-Systems (CPSoS)

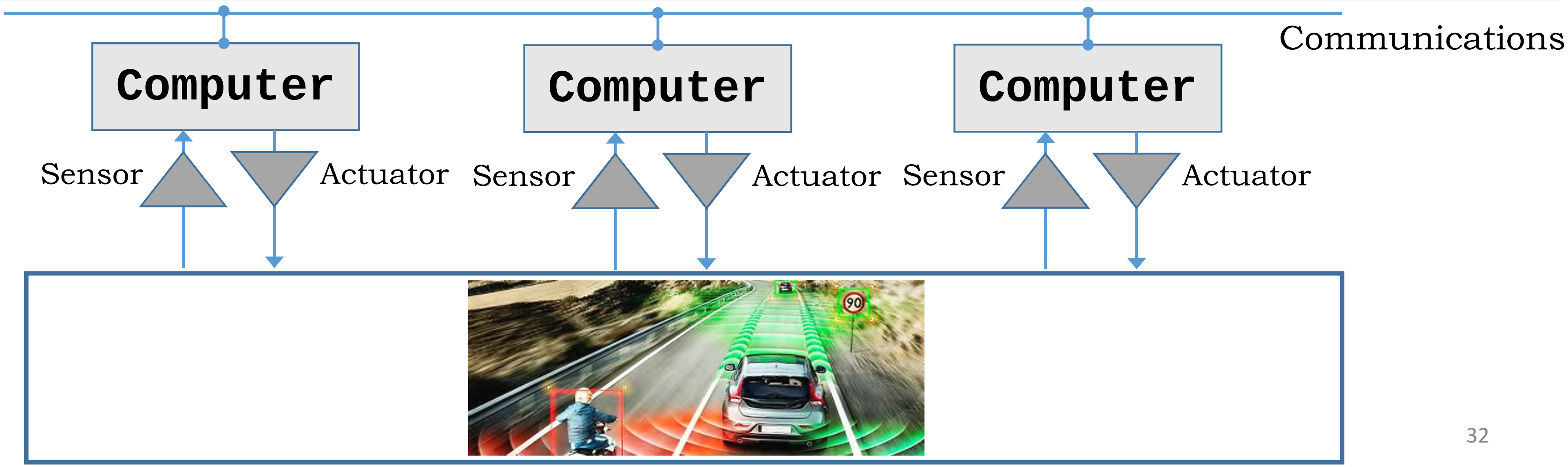
Cyber-Physical System-of-Systems (SoS)

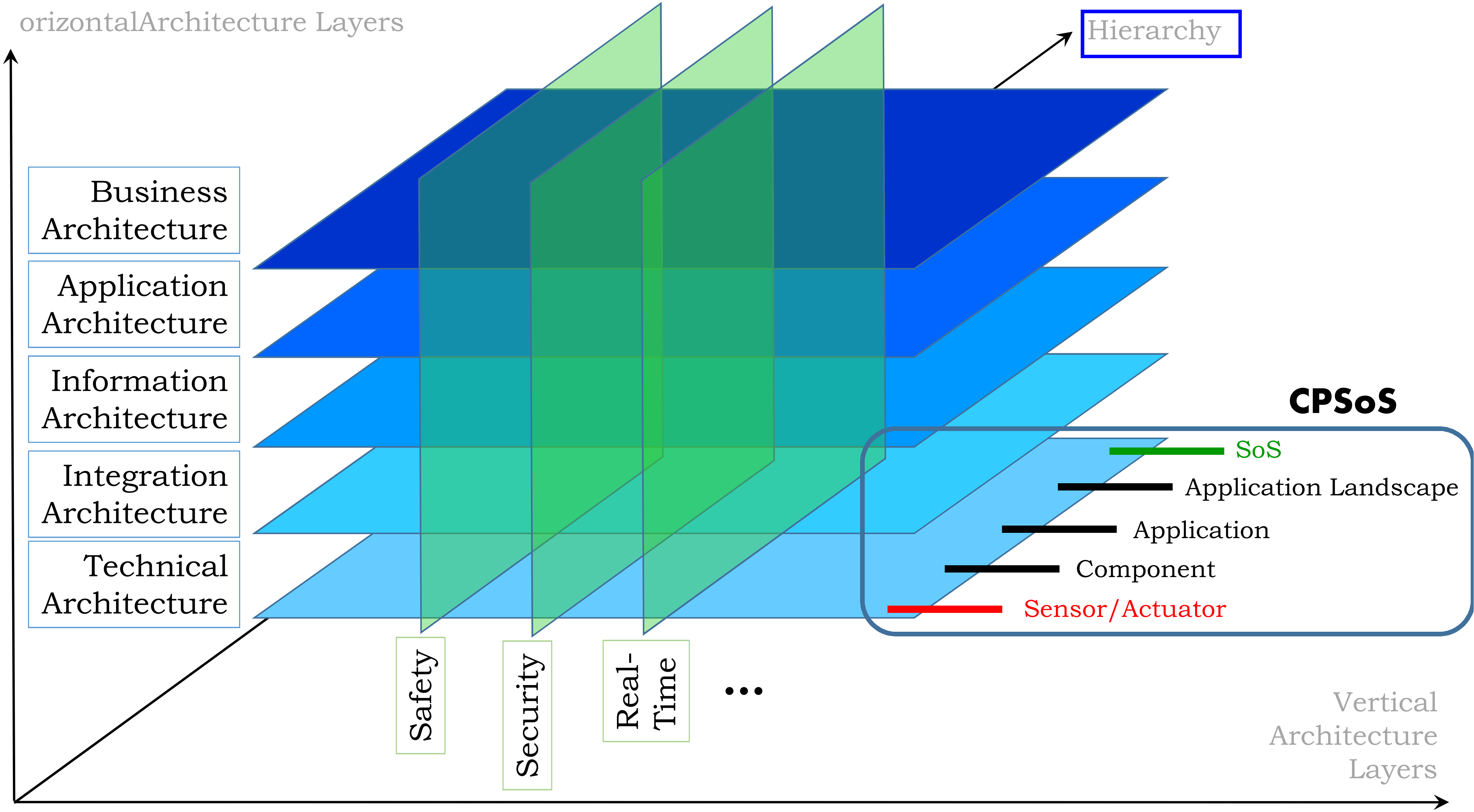
DEFINITIONS

A **cyber-physical system of systems (CPSoS)** brings together a set of *cyber-physical ooperating systems* for a task that none of the systems can accomplish on its own (= emergent property).

Each constituent cyber-physical system keeps its own management, goals, and resources while coordinating within the CPSoS and adapting to meet CPSoS goals.

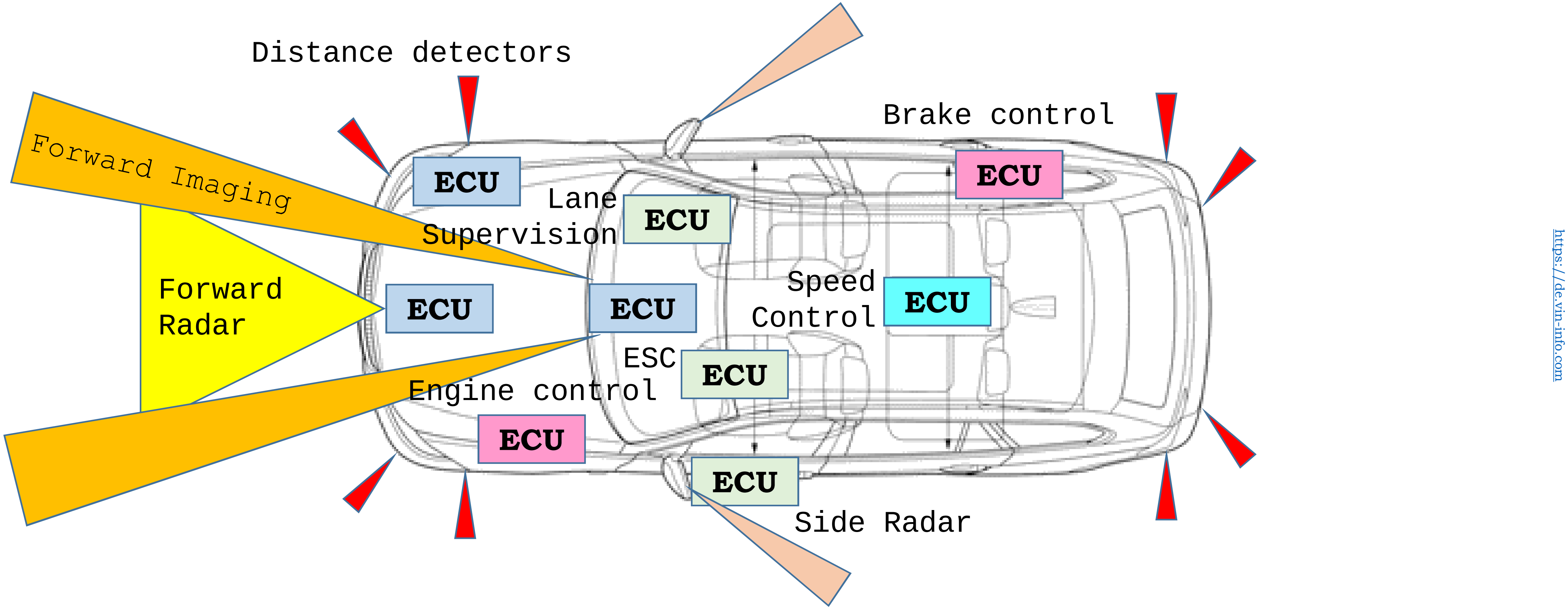
Adapted from ISO/IEC/IEEE 15288 Annex G





orizontalArchitecture Layers
Hierarchy
Business Architecture
Application Architecture
Information Architecture
Integration Architecture
Technical Architecture
CPSoS
SoS
Application Landscape
Application
Component
Sensor/Actuator
Safety
Security
Real-Time
...
Vertical Architecture Layers

Example: A modern car as CPSoS



A modern high-end car contains more than 100 networked ECUs (Electronic Control Units)

CPSoS Example: Roborace [Unmanned Automobile Racing]

https://www.crowdact.com

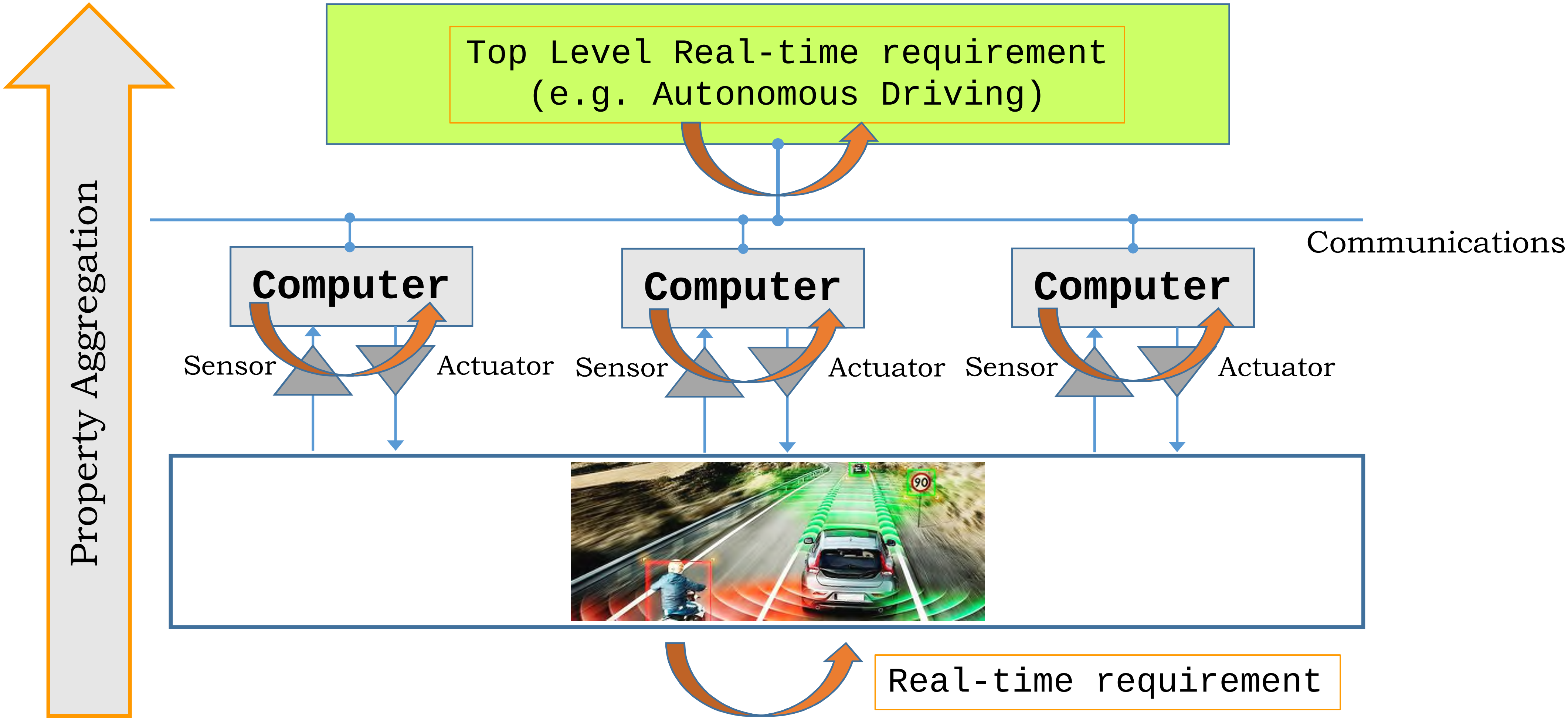
24 mechanically identical cars / 12 teams / F1-race circuits

NO drivers

Fully electric cars, V_{max} = 300 km/h

https://wi-images.condecdn.net

Winner: Cognitive and autonomic CPSoS-SW (24-Teraflops-Computers on-board)


Property Aggregation
Top Level Real-time requirement
(e.g. Autonomous Driving)
Communications
Computer
Computer
Computer
Sensor
Actuator
Sensor
Actuator
Sensor
Actuator
Real-time requirement

CPSoS Example: Autonomous earthquake search & rescue robots

https://spectrum.ieee.org

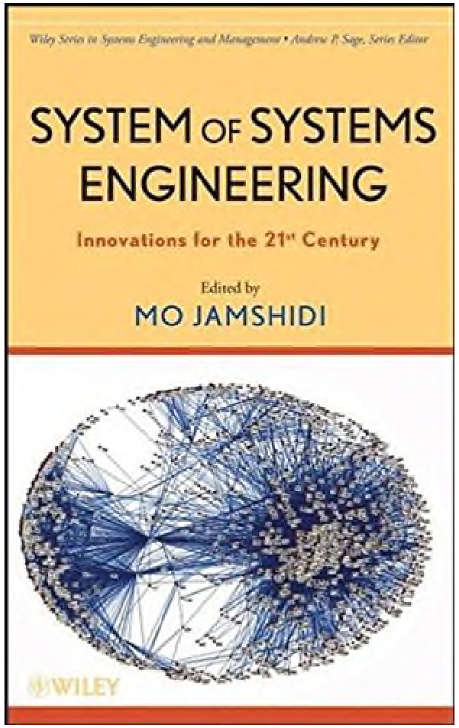
http://www.allonrobots.com

Recommendations

Cyber-Physical Systems-of-Systems (CPSoS)

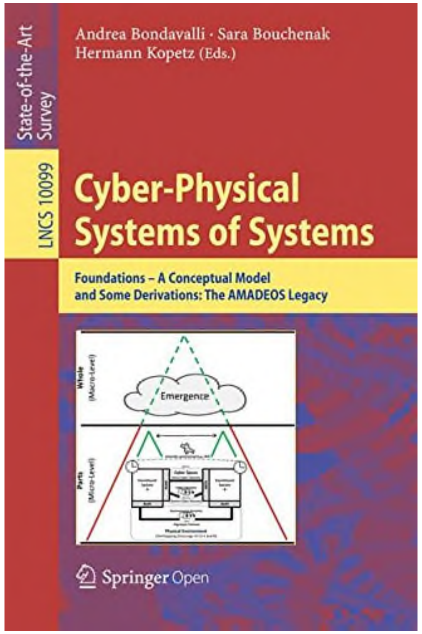
1. Dependability properties (safety, security, ...) always superse functionality requirements – in specifications, architecture, design, implementation, and operation
2. Implement monitoring capabilities – especially on the *interfaces* – to predict or detect abnormal or dangerous behaviour

Textbook



Mo Jamshidi (Editor):
Systems of Systems Engineering – *Innovations for the 21st Century*
John Wiley & Sons Inc., Hoboken, New Jersey, USA, 2009. ISBN 978-0-470-19590-1

Textbook



Andrea Bondavalli, Sara Bouchenak, Hermann Kopetz (Editors):
Cyber-Physical Systems of Systems:
Foundations - A Conceptual Model and Some Derivations (The AMADEOS Legacy)
Springer-Verlag, Germany, 2016. ISBN 978-3-319-47589-9

Cloud Computing

DEFINITIONS

Cloud computing …

- is a ***model*** for enabling ubiquitous, convenient, on-demand access:
- to a shared pool of configurable ***computing resources*** (e.g., networks, servers, storage, applications, and services)
- that can be rapidly provisioned and released
- with minimal management effort or service provider interaction

US National Institute of Standards and Technology
http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf

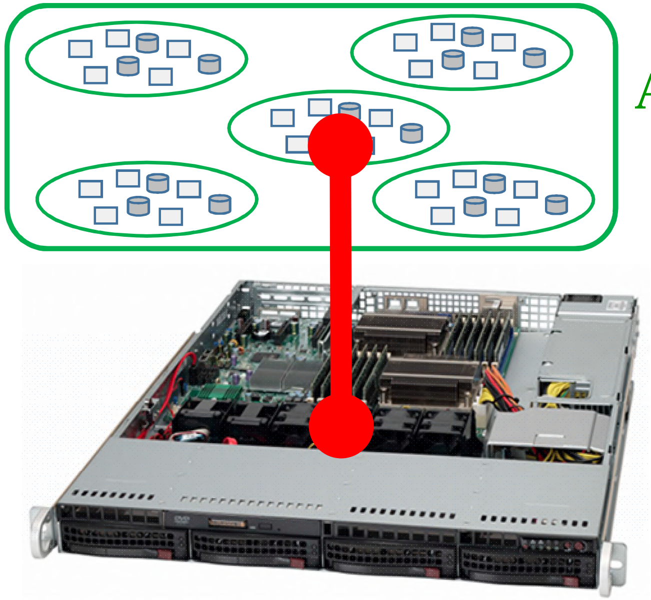
http://www.telegraph21.com

Iron Age

http://www.freiburg.de

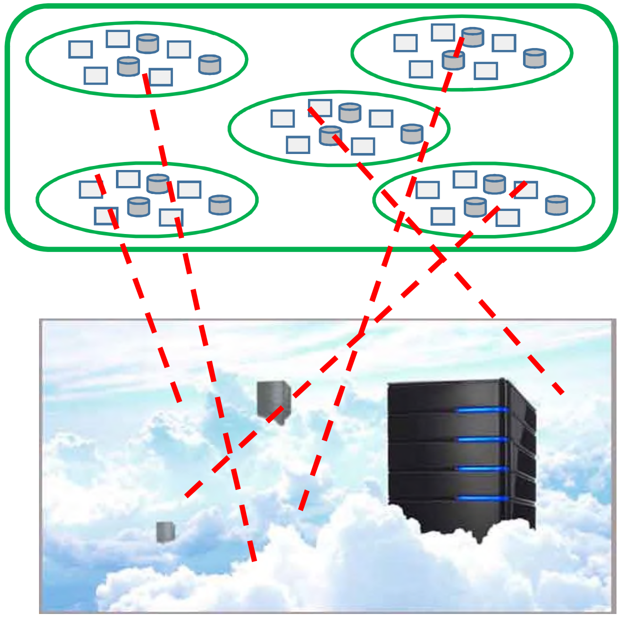
Cloud Age

http://blog.schneider-electric.com



https://www.snelserver.com

Application Landscape



http://www.telegraph21.com

Cloud-based computing

Enterprise Cloud Computing

http://www.telegraph.co.uk

Embedded Cloud Computing

Enterprise Cloud Computing

Enterprise Cloud Computing is a ***business model*** with promising commercial and technical advantages. It relies on using 3rd party IT-services delivered via the Internet instead of in-house IT-installations.

⇒ Enterprise IT **deployment-architecture** for the next decades

- On-demand use of IT-capabilities
- Massive reduction of IT capital investment
- Significant reduction of (low level) IT staff
- Access to modern technology and services

Advantages of Cloud Computing

http://diginetinfosystems.com

Risks of Cloud Computing

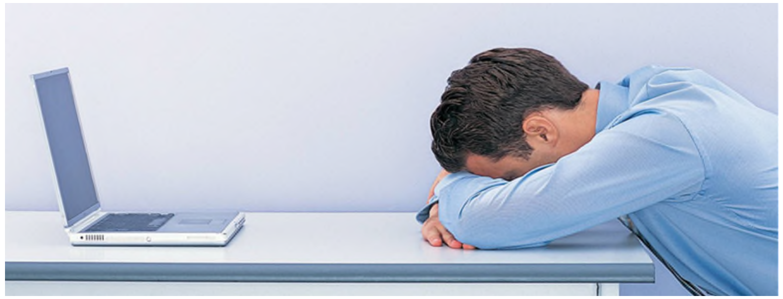
http://www.ultimatetech.org

Security

http://ex-c.co.uk

Loss of Control

Loss/Theft of Company Data



http://www.iperiusbackup.net

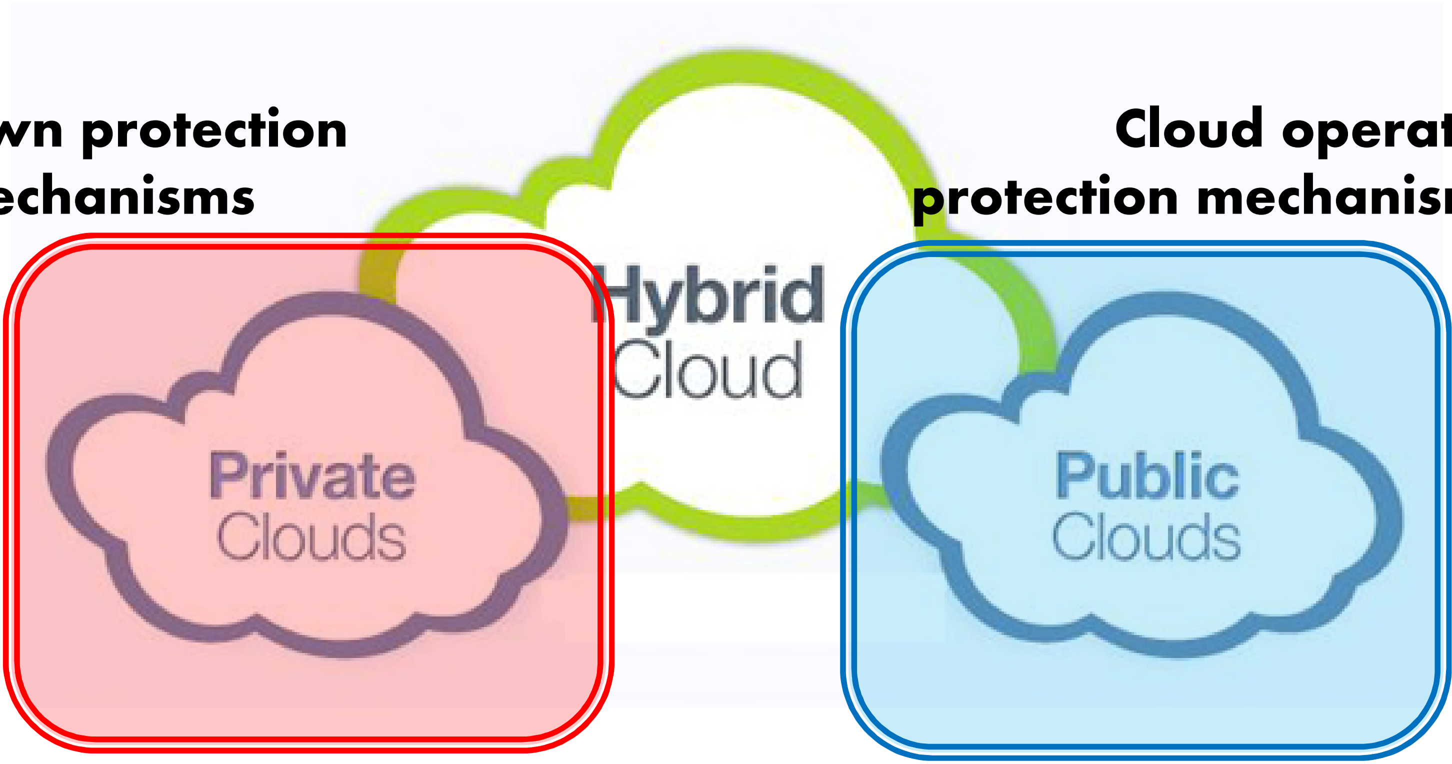
http://lionfield.com

Disaster Recovery

Risks of Cloud Computing

Own protection mechanisms

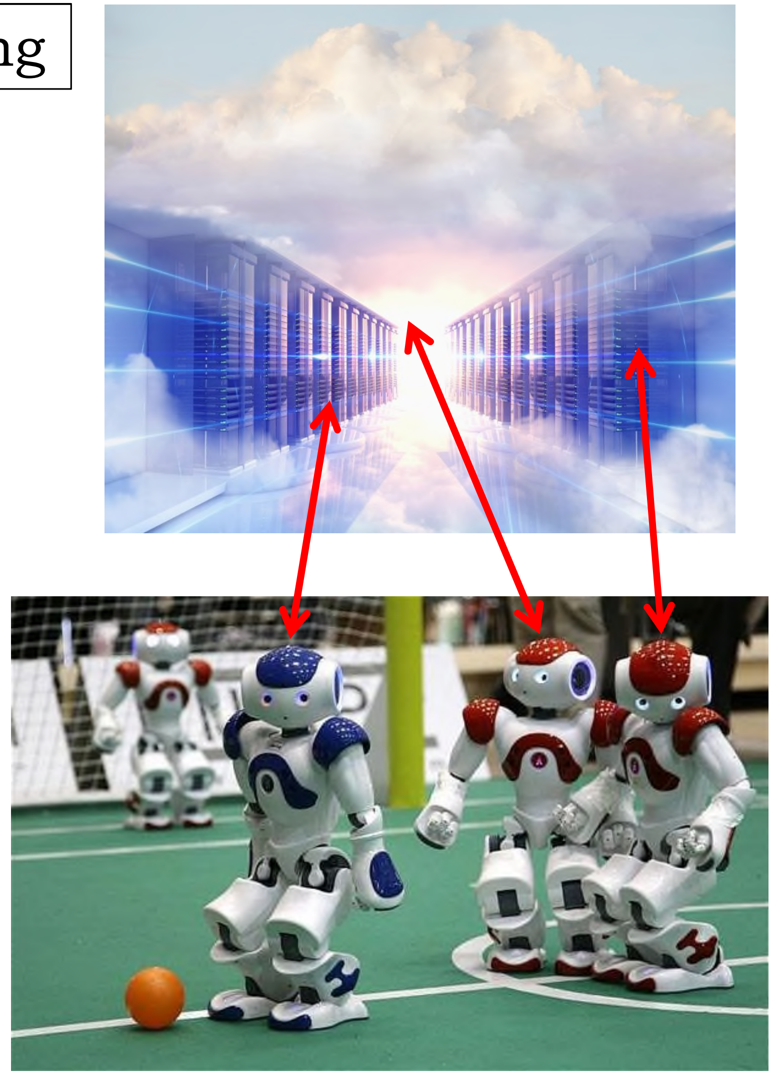
Cloud operator protection mechanisms



http://www.itbriefcase.net

Embedded Cloud Computing

http://www.manager-magazin.de



Distributed systems *communicate* and *synchronize* in real-time via the cloud

Distributed systems use the power of *cloud resources*

http://www.telegraph.co.uk

Embedded Cloud Computing

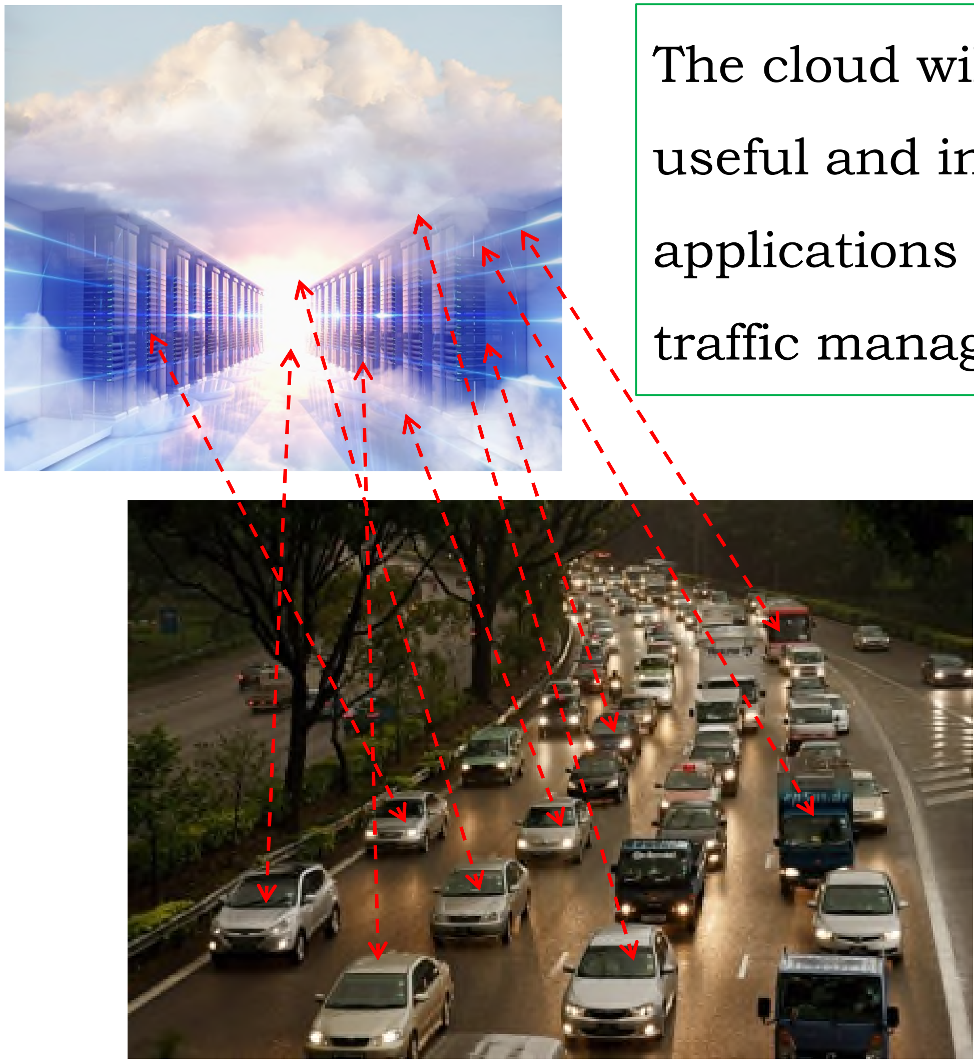
Cloud Robotics is the application of the cloud computing concept to **robots**. This means using the Internet to augment the robots capabilities by off-loading computation and providing services on demand

⇒ Interesting and active research area:

- Cloud Robotics
- Collaborative Manufacturing
- Intelligent Traffic Management
- etc.

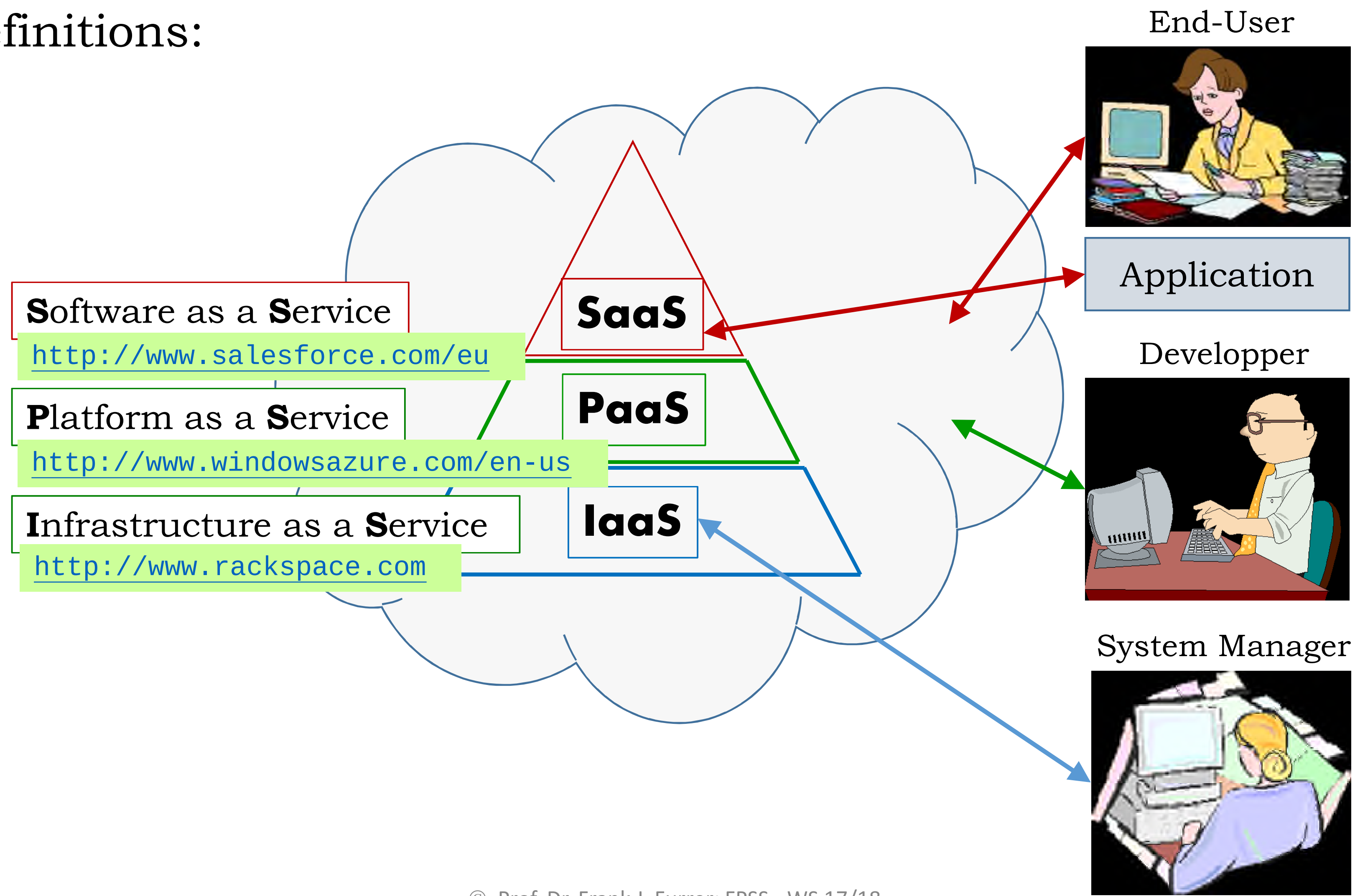
http://www.manager-magazin.de

https://gigaom.com



The cloud will enable many useful and interesting applications (e.g. optimized traffic management)

Cloud Definitions:



Cloud Definitions:

Cloud Service **Provider**

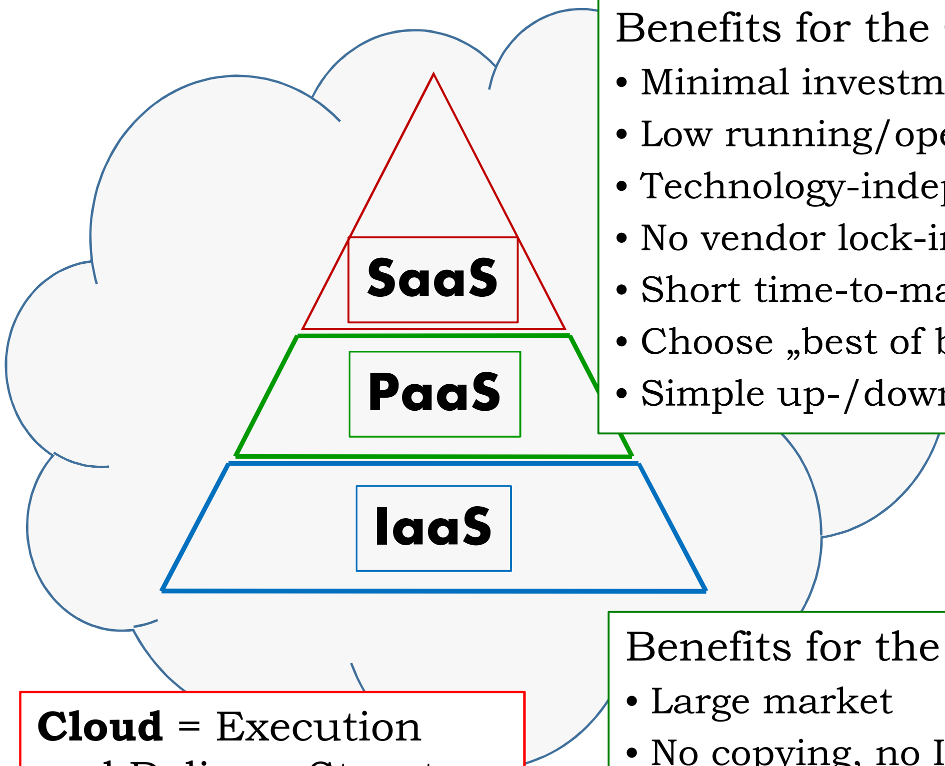
Contract

Cloud Service **Consumer**

http://1.bp.blogspot.com

http://www.vision-training.com

Cloud **Benefits**:



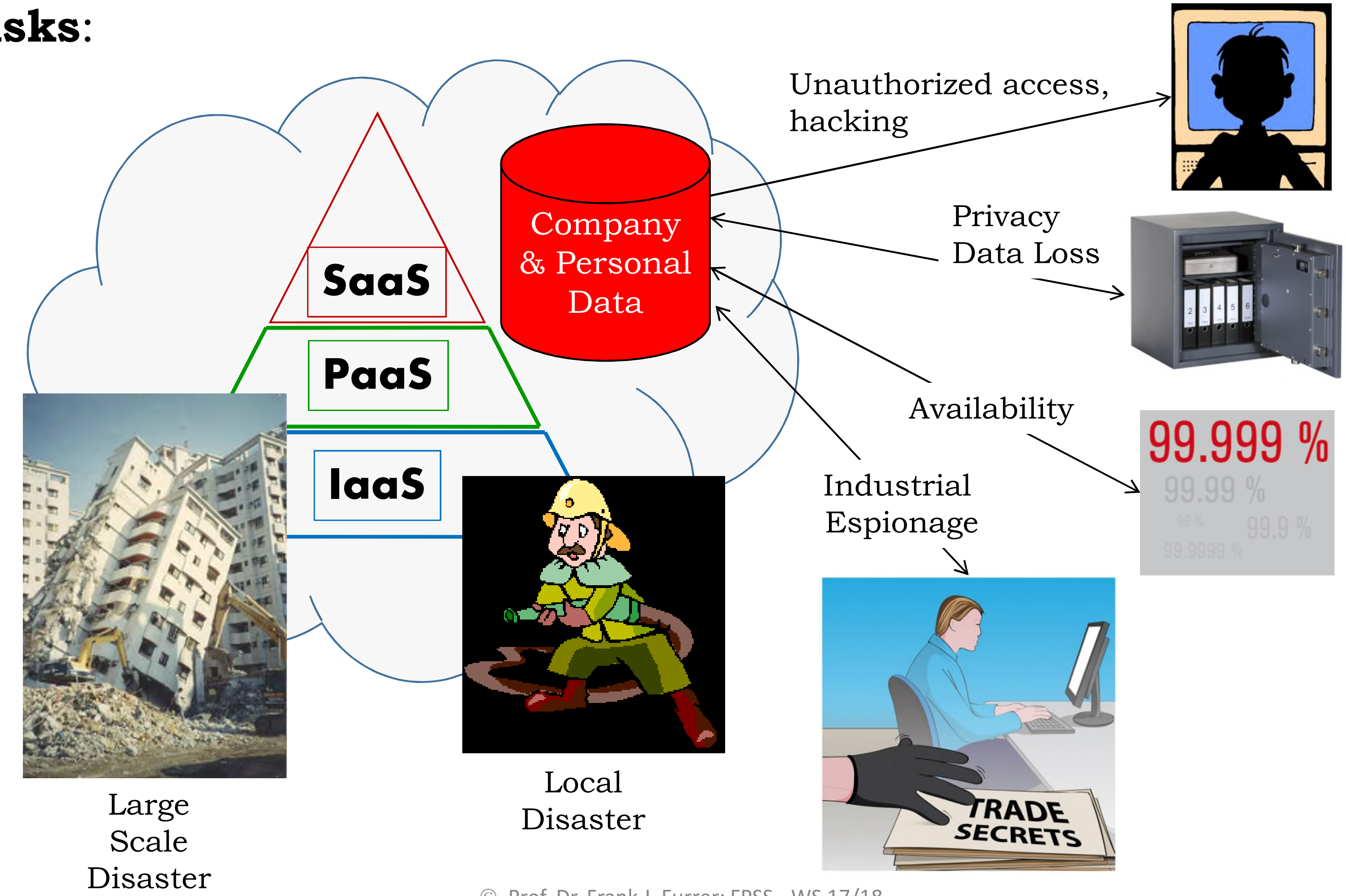
Benefits for the **Cloud Service Consumers**:
- Minimal investment
- Low running/operational cost
- Technology-independent
- No vendor lock-in
- Short time-to-market („assemble“ instead of „build“)
- Choose „best of breed“
- Simple up-/downscaling

Cloud = Execution and Delivery Structure

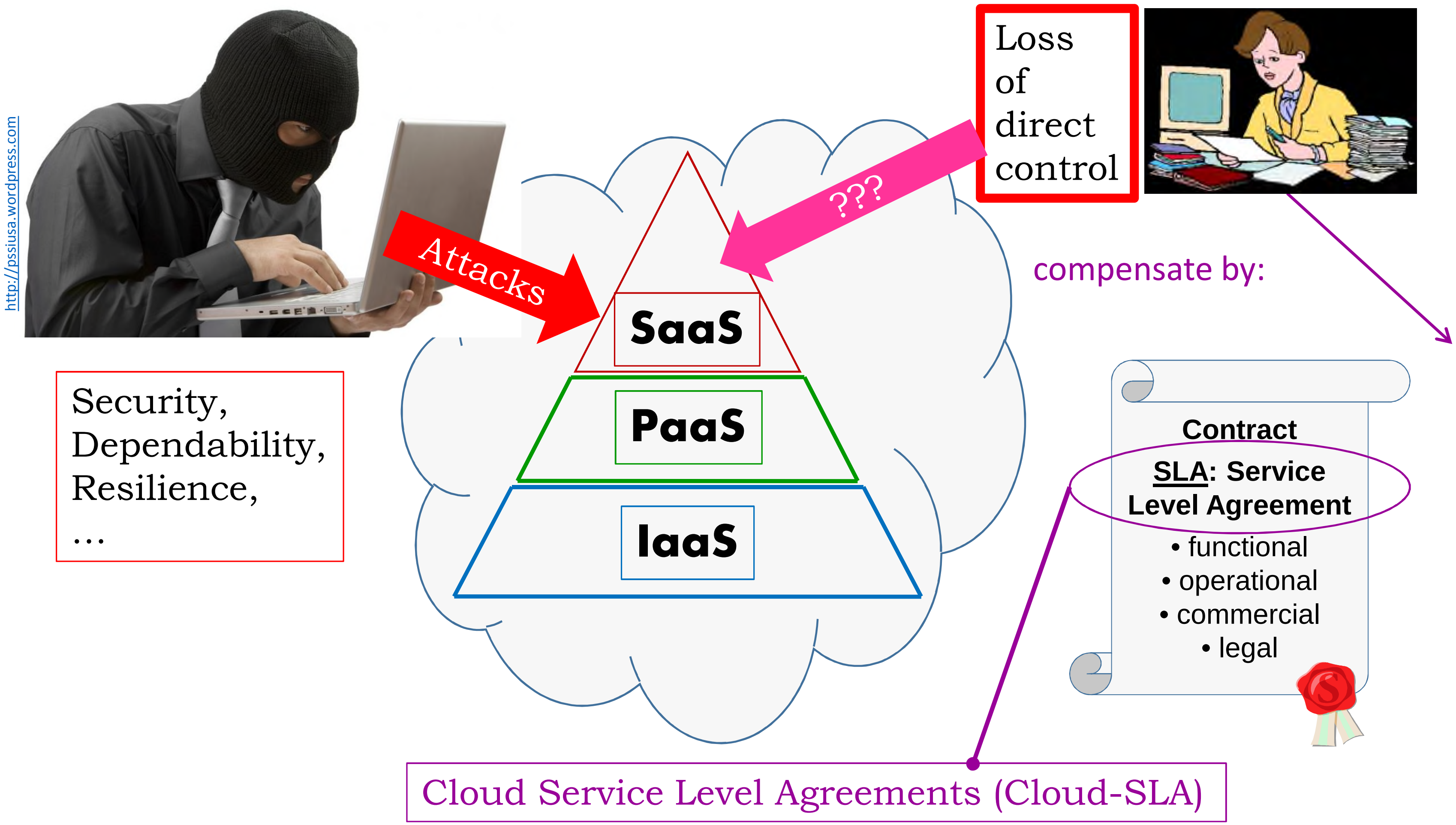
Cloud Usage = Commercial decision (Business model)

Benefits for the **Cloud Service Providers**:
- Large market
- No copying, no IPR disclosure
- Economy of scale
- Interesting new business models
- Specialization

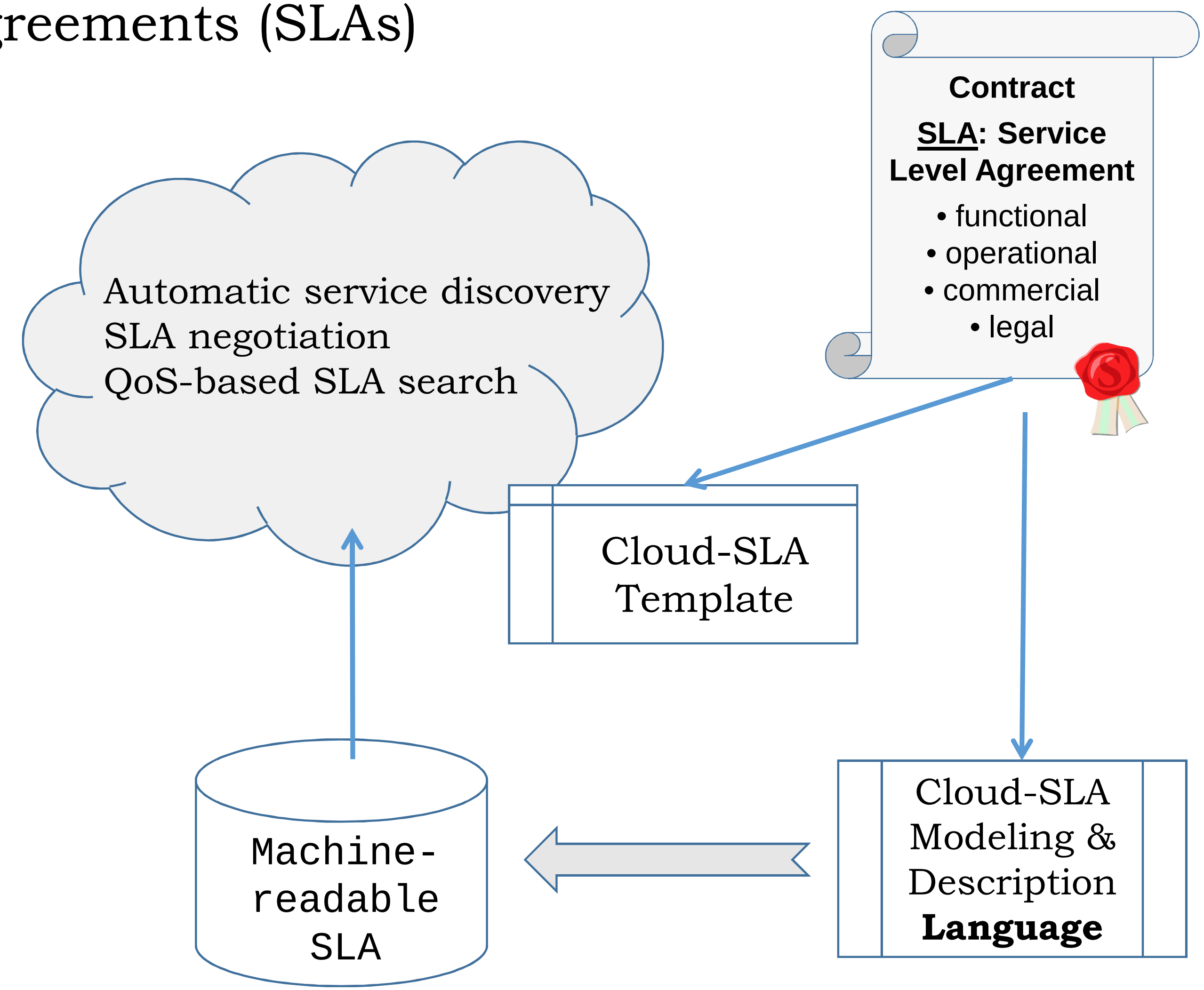
Cloud **Risks**:


SaaS
PaaS
IaaS
Company & Personal Data
Unauthorized access, hacking
Privacy Data Loss
Availability
99.999 %
99.99 %
99.9 %
Industrial Espionage
TRADE SECRETS
Local Disaster
Large Scale Disaster

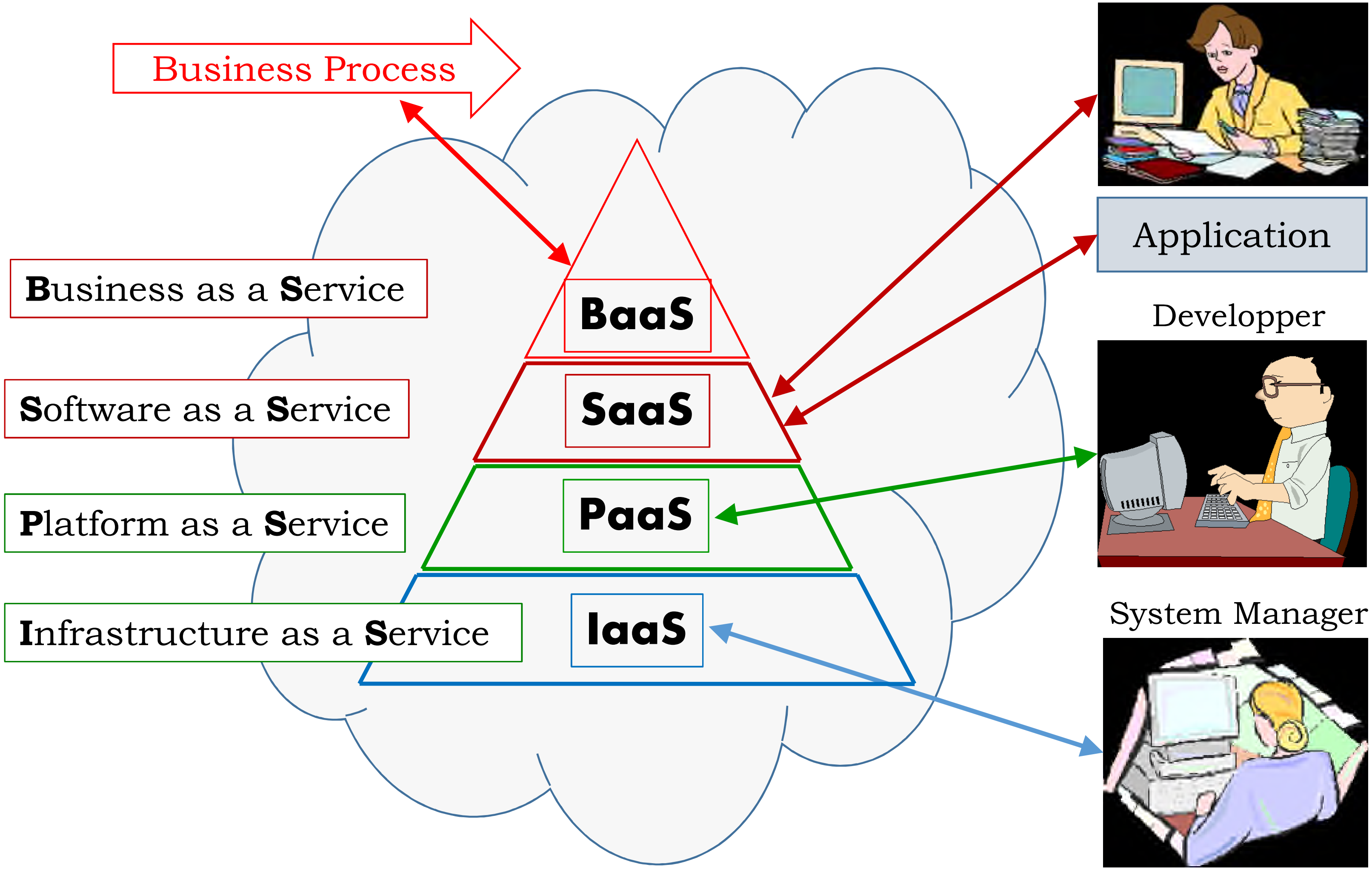
Cloud **Risks**:


http://pssiusa.wordpress.com
Attacks
???
Loss of direct control
compensate by:
SaaS
PaaS
IaaS
Security,
Dependability,
Resilience,
…
Contract
SLA: Service Level Agreement
• functional
• operational
• commercial
• legal
Cloud Service Level Agreements (Cloud-SLA)

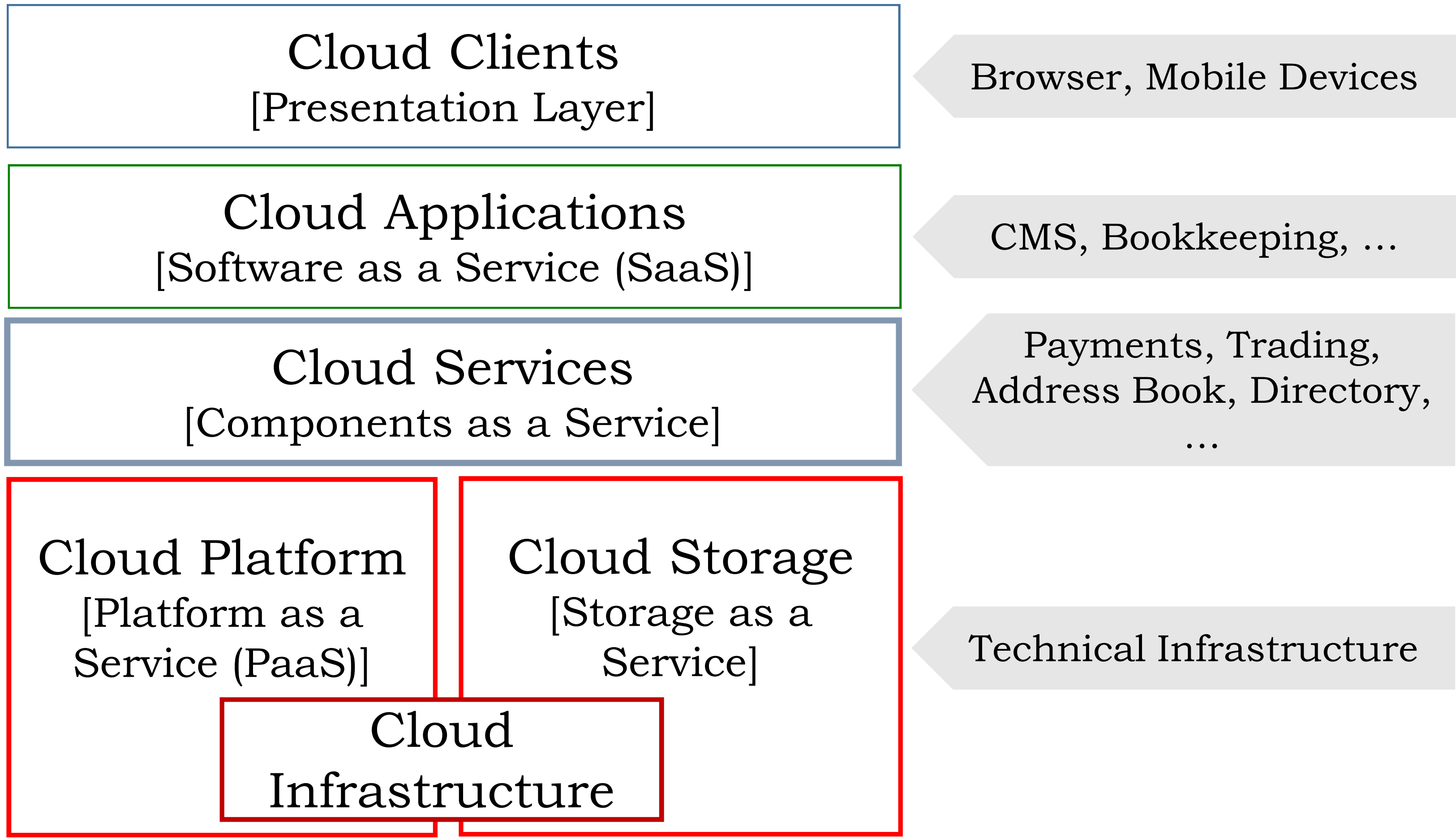
Cloud Service Level Agreements (SLAs)



Cloud Definitions:



Cloud Computing Stack:



Mahmood, 2011

Cloud Responsibilities

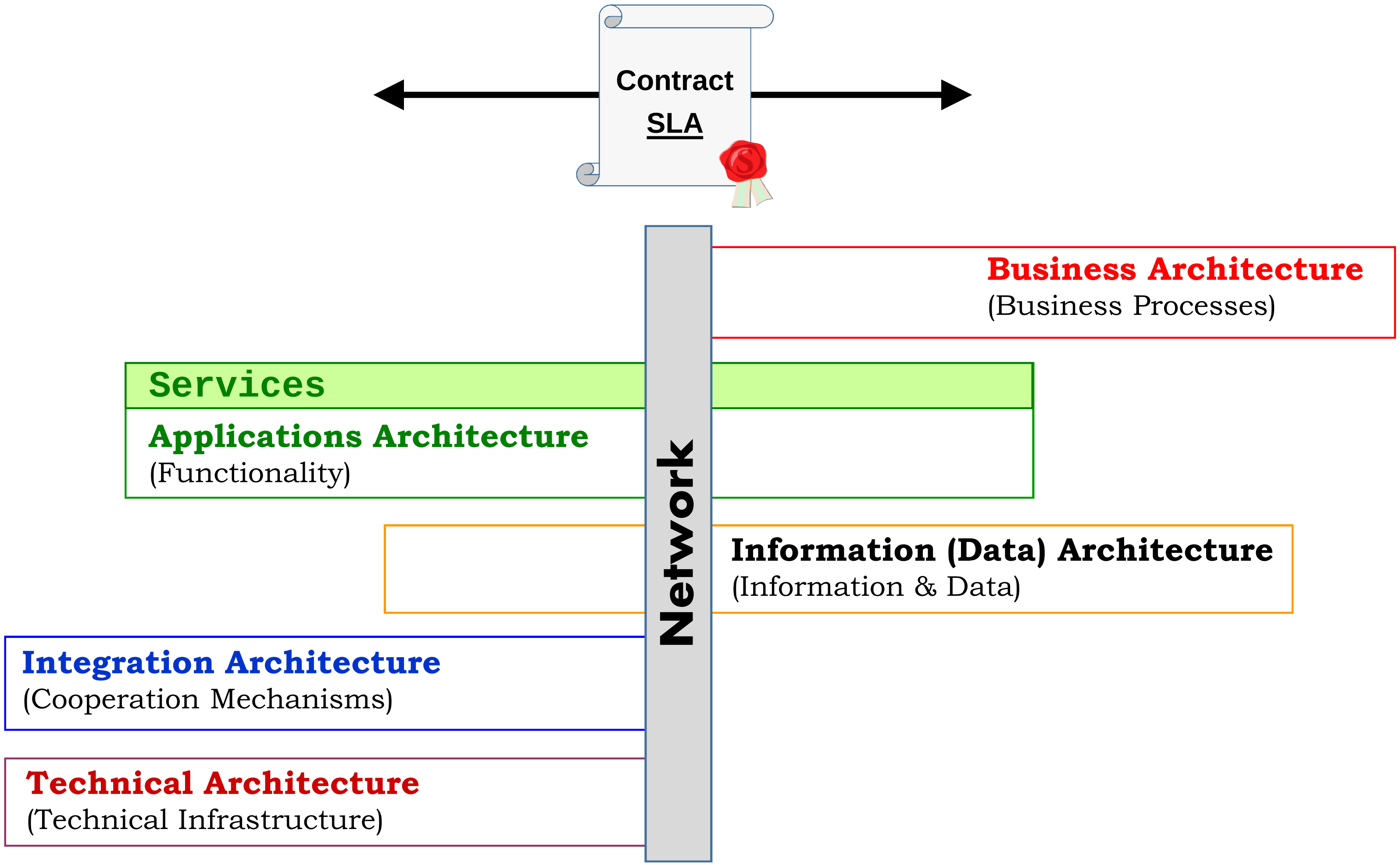
http://kriszha.com

cloud SERVICE PROVIDER

http://www.gograph.com

Provider	**Consumer**
Service **architecture**	Business model
Industry standards	Enterprise cloud **architecture**
Effective & efficient	Risk analysis
Agile	Contracts
Security	Privacy ?
Disaster recovery	Business Continuity Planning
Cost models	Monitoring
Responsible Cloud Infrastructure	**Enterprise Cloud Service Architecture**

Cloud: Influence on Architecture



The cloud paradigm offers very interesting commercial and technical ***benefits***

When using IaaS, PaaS, SaaS or BaaS („cloudification“) a ***loss*** of direct control results

Many of the quality properties (Security, availability, privacy etc.) are mainly under the control of the cloud service provider

The loss of direct control must be compensated by clear, explicit, and legally binding ***contracts***

Focus shifts from „building“ to „assembling“ – and needs new, different engineering + architecture processes

Recommendations

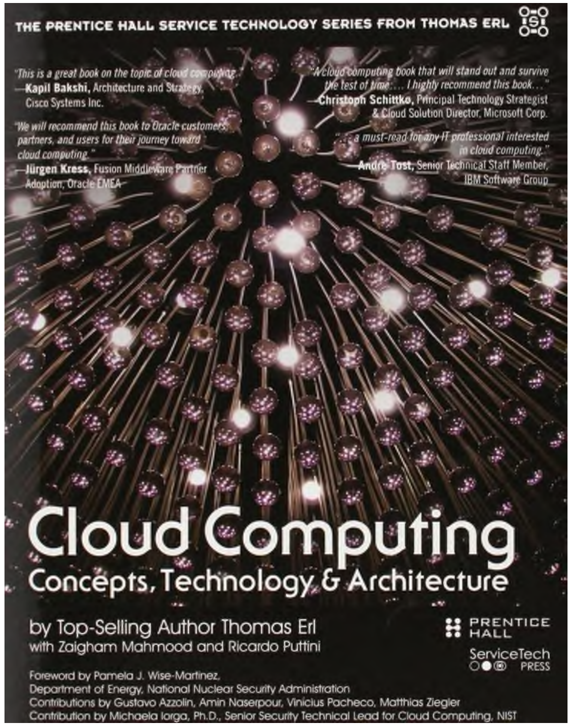
Architecture Recommendation for Cloud Service *Providers*:

1. Implement the architecture principles as presented in this lecture
2. Deliver the cloud-services via established, accepted industry-standards
3. Provide transparency on your architecture, implementation and evolution
4. Give factual & contractual assurance for the quality properties (dependability, availability, privacy, disaster-recovery, performance etc.)

Architecture Recommendation for Cloud Service *Consumers*:

1. Compensate the loss of transparence by requiring sufficient information about cloud service provider architecture, quality properties etc.
2. Compensate the lack of control by clear, explicit, legally binding Cloud-SLAs (Cloud service level agreements)
3. Insist on established, accepted industry-standards for the delivery of all cloud-services

Textbook

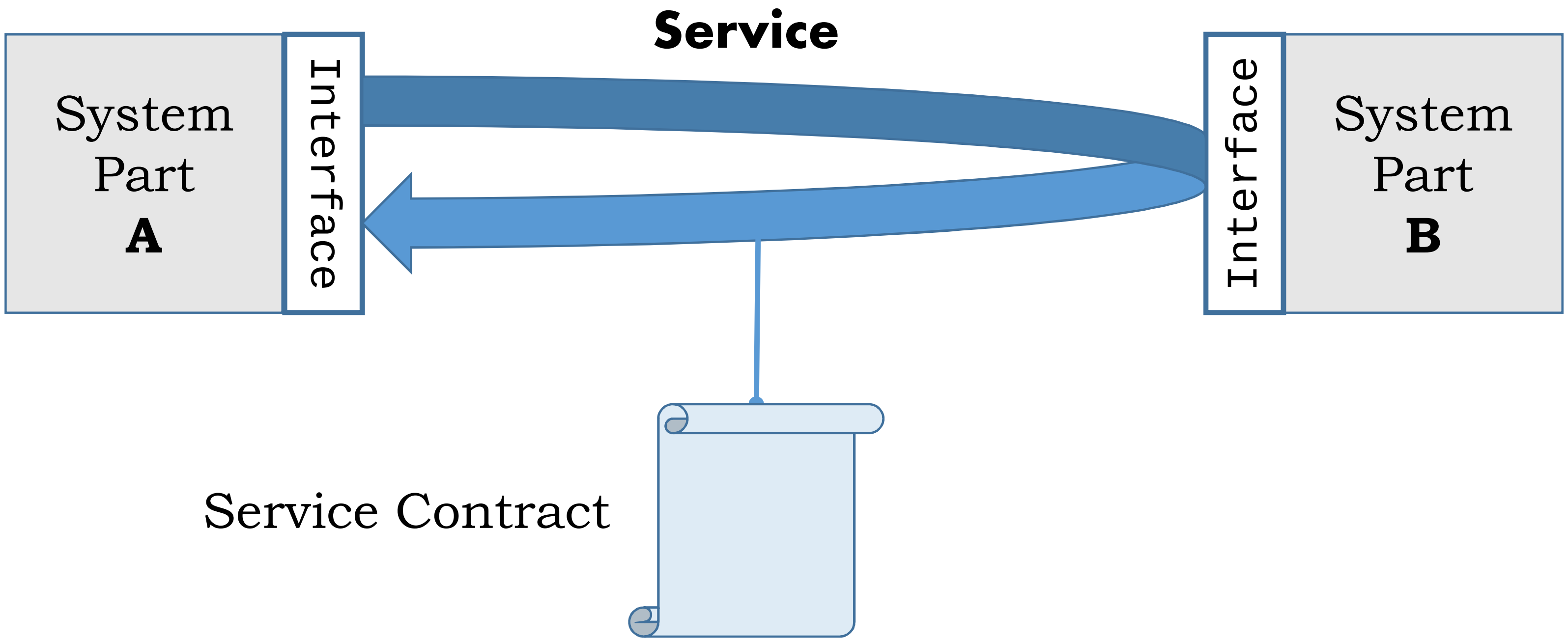


Thomas Erl, Ricardo Puttini, Zaigham Mahmood:
Cloud Computing – *Concepts, Technology & Architecture*
Prentice Hall Inc., USA, 2013. ISBN 978-0-133-38752-0

Textbook

Bill Wilder:
Cloud Architecture Patterns
O'Reilly and Associates, USA, 2012. ISBN 978-1-449-31977-9

Microservices



	• Functionality • Operational parameters • Commercial Conditions

Services implement:

- Good partitioning
- Excellent encapsulation
- Loose coupling

Coarse-grained service

Granularity

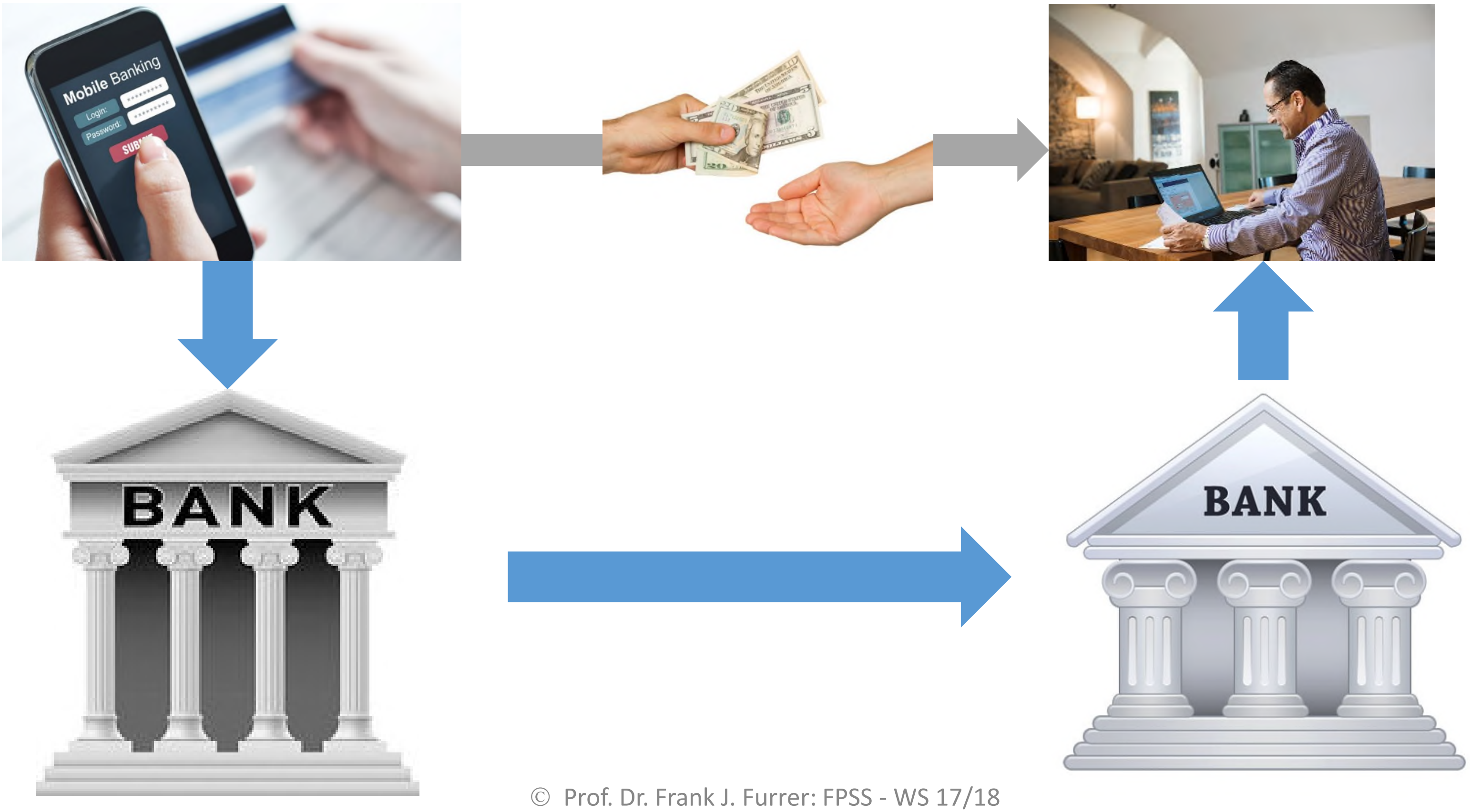
Fine-grained service

http://lordsandknights.enjoyed.today/common/fansite_kit/units/OxCart.png

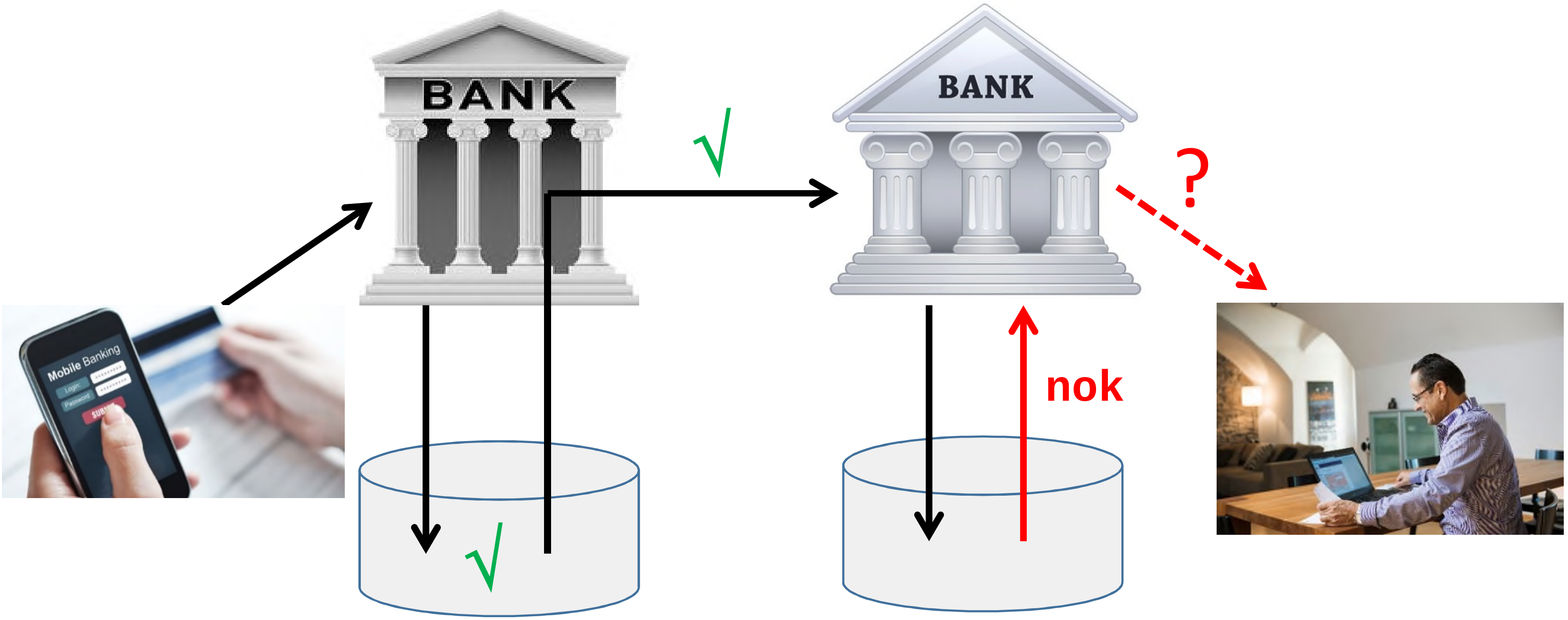
http://www.prodogroomingsupplies.com

Example: Coarse-grained service (1/4)

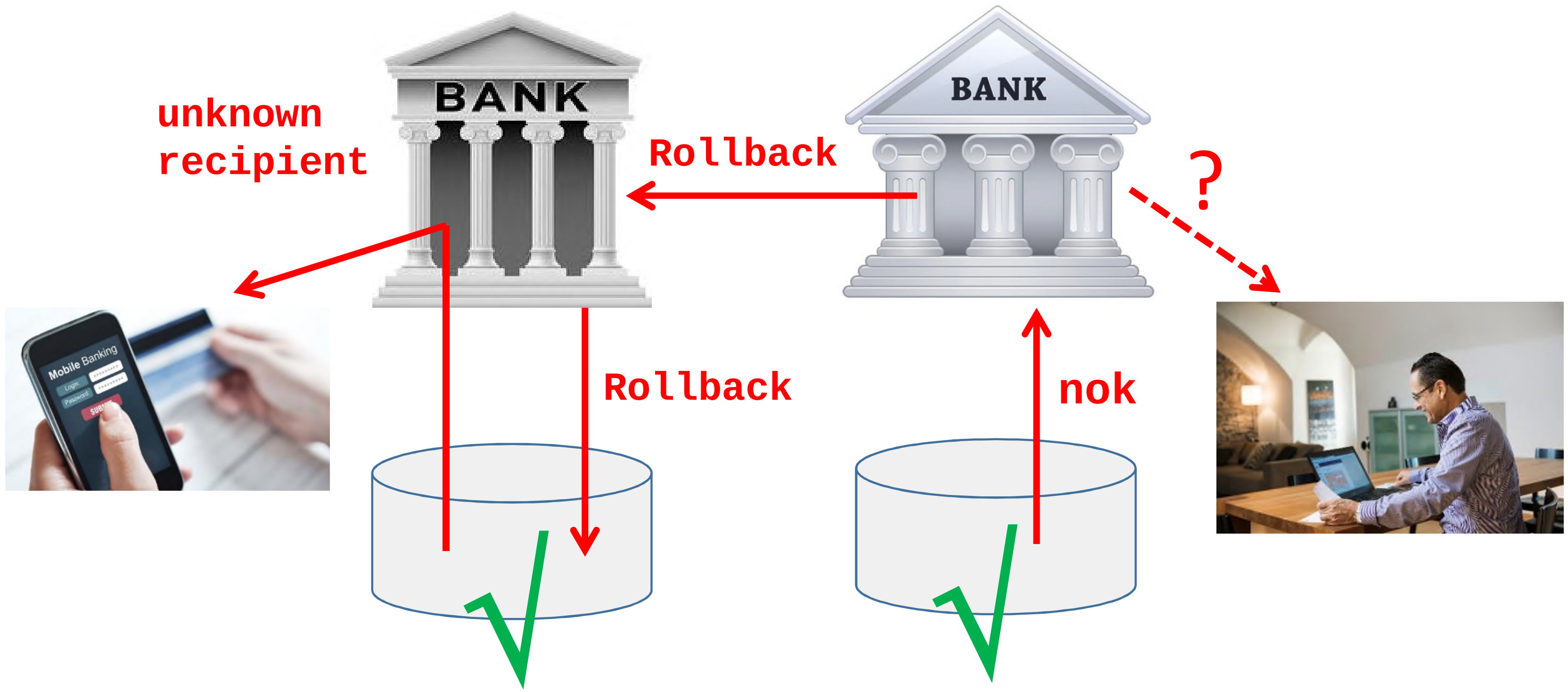
Interbank Electronic Money-Transfer:



Example: Coarse-grained service (2/4)

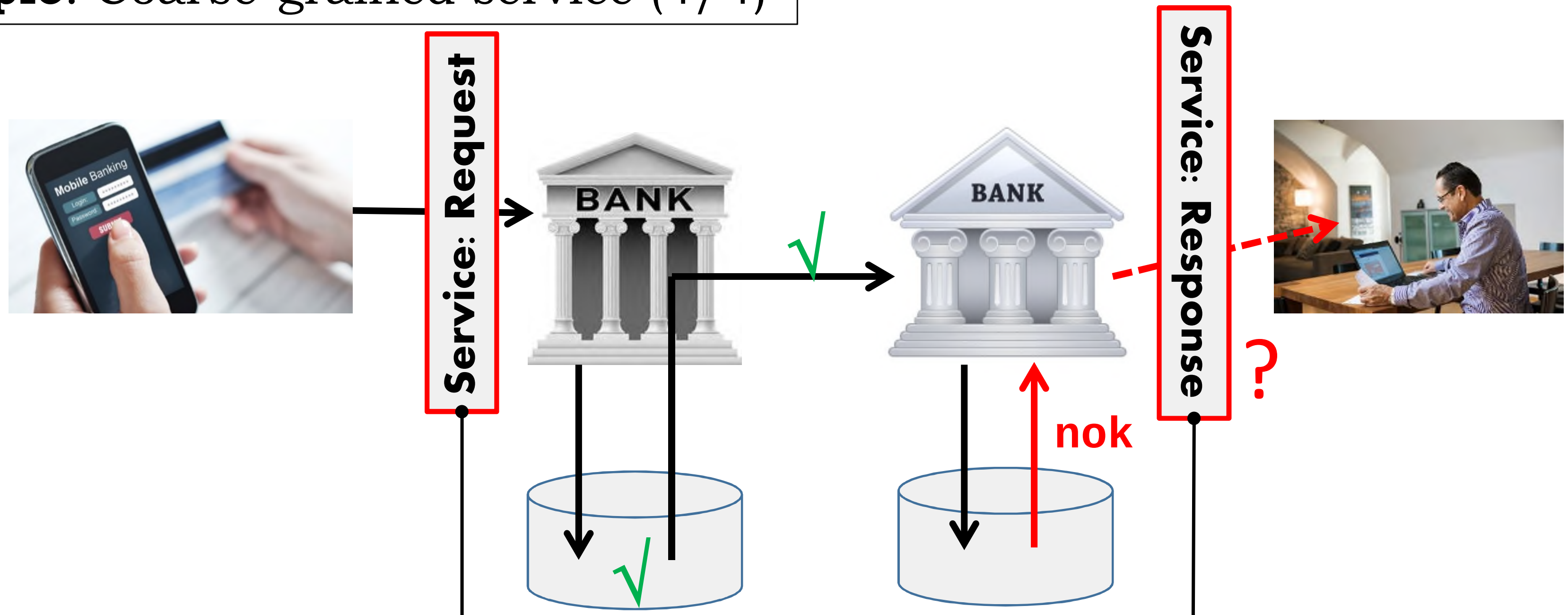


Example: Coarse-grained service (3/4)



All databases are correct and consistent

Example: Coarse-grained service (4/4)

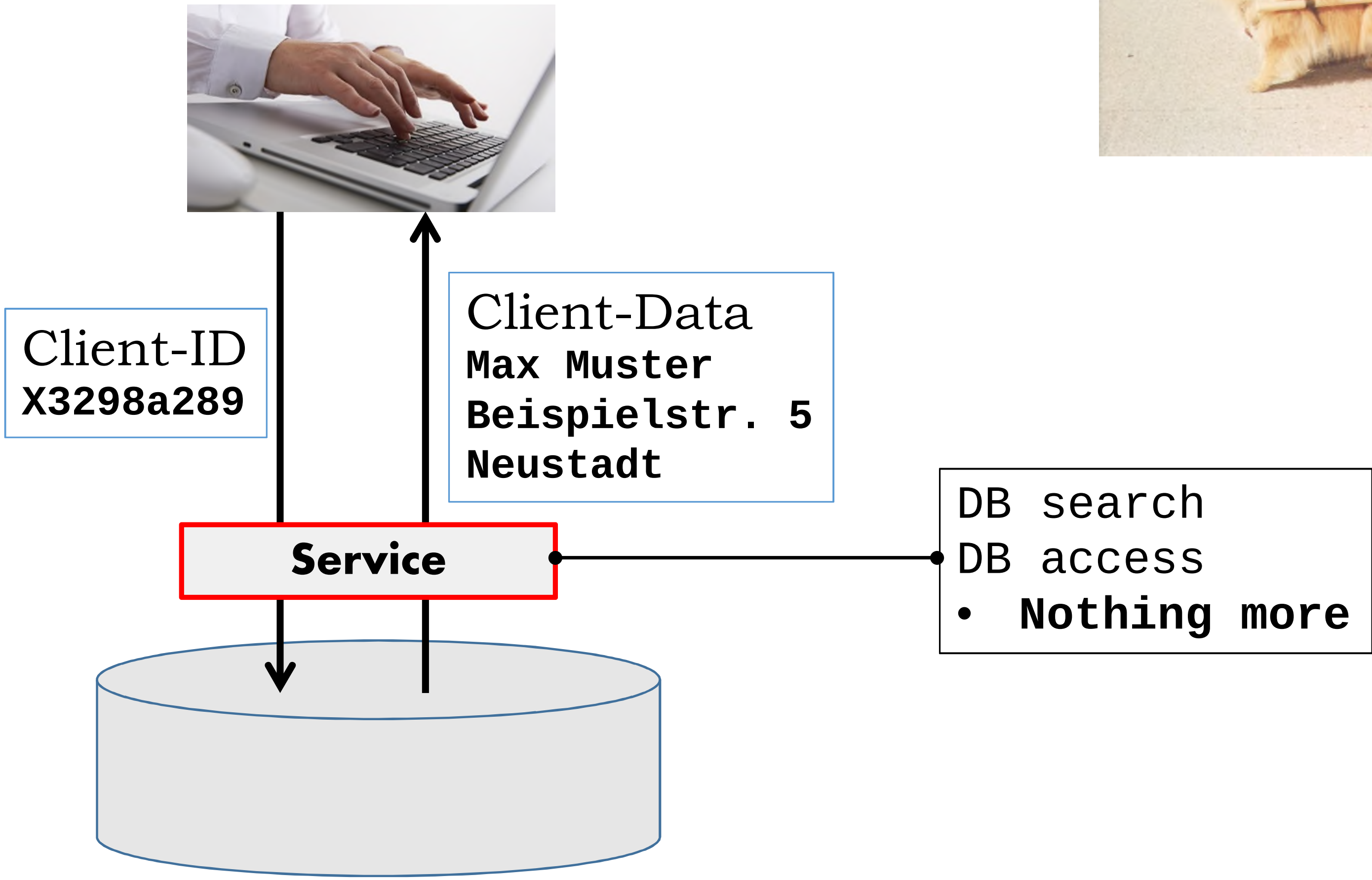


Authorization
Check balance
Transfer
Process feedback
Rollback

System Consistency

Authorization
Check account
Transfer denied
Generate feedback
Rollback

Example: Fine-grained service (1/x)



Coarse-grained service

Granularity

Fine-grained service

Service Usage

Service

Functionality	Non-functional properties	System-Properties

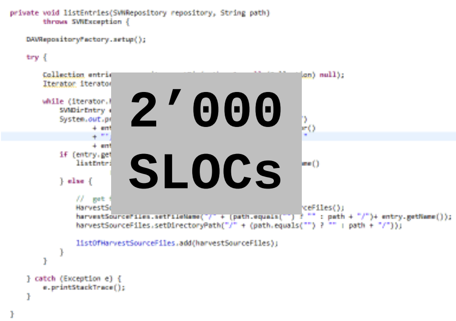
Functionality
- Computation
- Data access
- Data transfer
- Control transfer

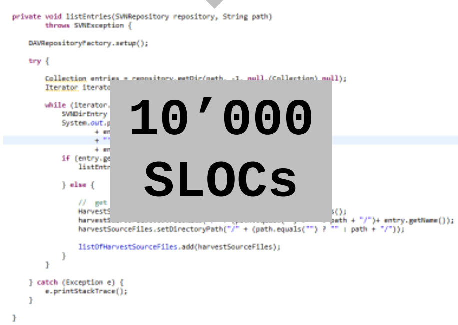
Non-functional properties
- Error handling
- Fault processing
- Security
- Safety, …
- Parallelism
- Scalability
- …

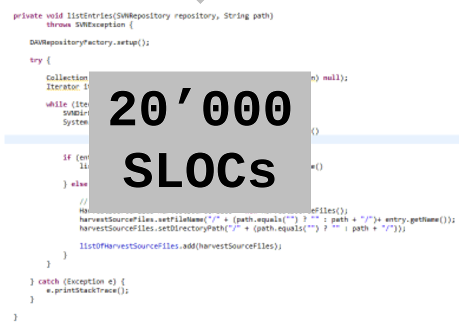
System-Properties
- Synchronization
- Consistency
- Monitoring
- Auditability
- Accountability
- Versioning
- Recovery
- …

Service

Functionality	Non-functional properties	System-Properties
• Computation • Data access • Data transfer • Control transfer	• Error handling • Fault processing • Security • Safety, … • Parallelism • Scalability • …	• Synchronization • Consistency • Monitoring • Auditability • Accountability • Versioning • Recovery • …



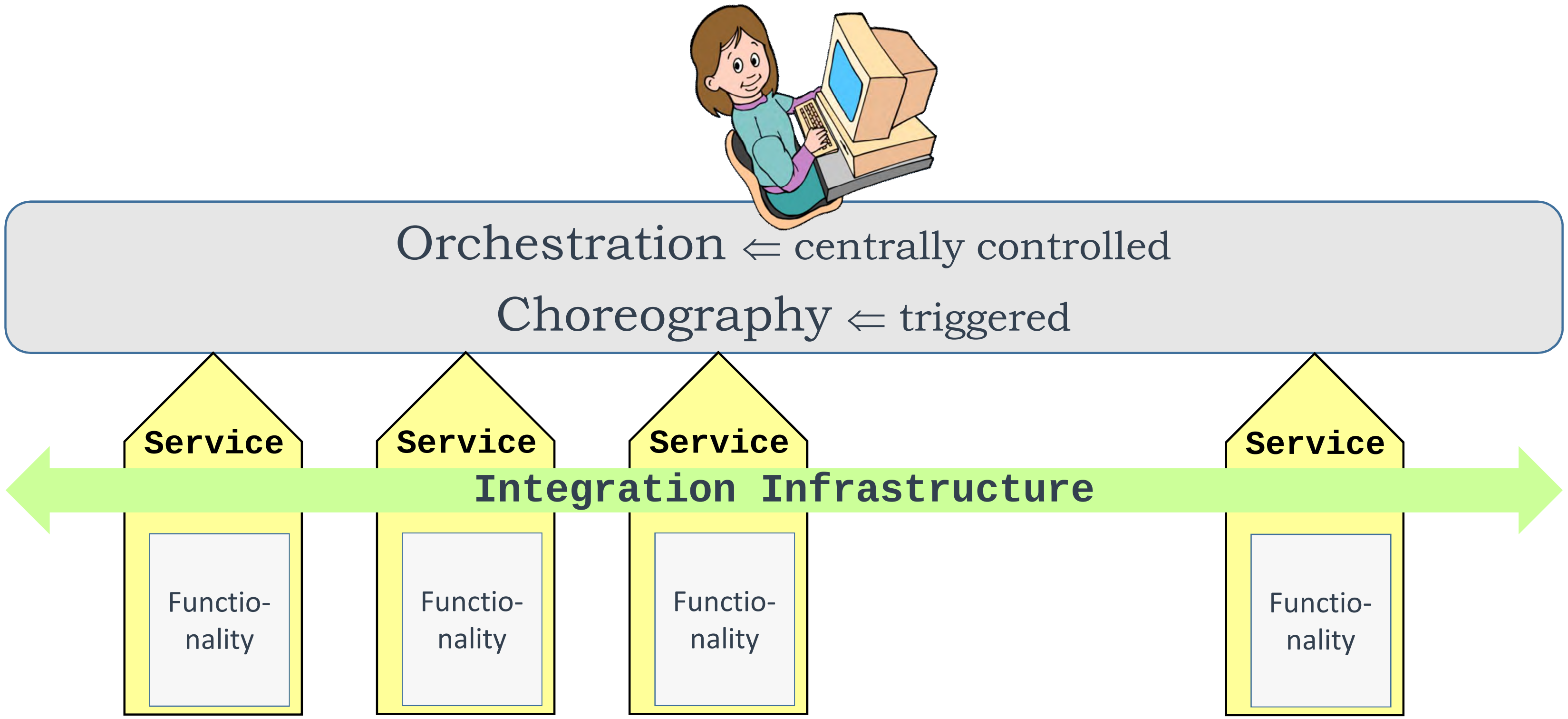




Microservice Principles

DEFINITIONS

Microservices are ***small***, ***autonomous***, ***independently deployable*** services that work together using an ***integration infrastructure***



Future-Proof Software-Systems [Part 3C]

Specifi-cation → Development Evolution → Operation (24/7)

Micro-service

Micro-service

Micro-service

Micro-service

Teams

Management

http://publishinginsider.net

Microservice Principles

- A microservice is «***small***» (various, fuzzy definitions)
- A microservice does ***one*** thing – and does it well
- A microservice works with ***business objects***
- A microservice respects all ***architecture principles***

  (especially partitioning, encapsulation, loose coupling and no reduncancy)
- A microservice is consistently ***embedded*** into the enterprise architecture ⇐ *Importance of overall architecture!*

  (Structure, technology, security, safety, …)
- A microservice is independently ***evolvable*** and ***deployable***
- A microservice can be ***monitored*** as part of the whole
- A microservice has a defined ***owner***, embedded in the company governance structure

CAUTION: Adopting microservices requires an adequate company organization

• **Maximize team autonomy**: Create an environment where teams can get more done without having to coordinate with other teams.
• **Optimize for development speed**: Hardware is cheap, people are not. Empower teams to build powerful services easily and quickly.
• **Focus on automation**: People make mistakes. More systems to operate also means more things that can go wrong. Automate everything.
• **Provide flexibility without compromising consistency**: Give teams the freedom to do what's right for their services, but have a set of standardized building blocks to keep things sane in the long run.
• **Built for resilience**: Systems can fail for a number of reasons. A distributed system introduces a whole set of new failure scenarios. Ensure measures are in place to minimize impact.
• **Simplified maintenance**: Instead of one codebase, you'll have many. Have guidelines and tools in place to ensure consistency.

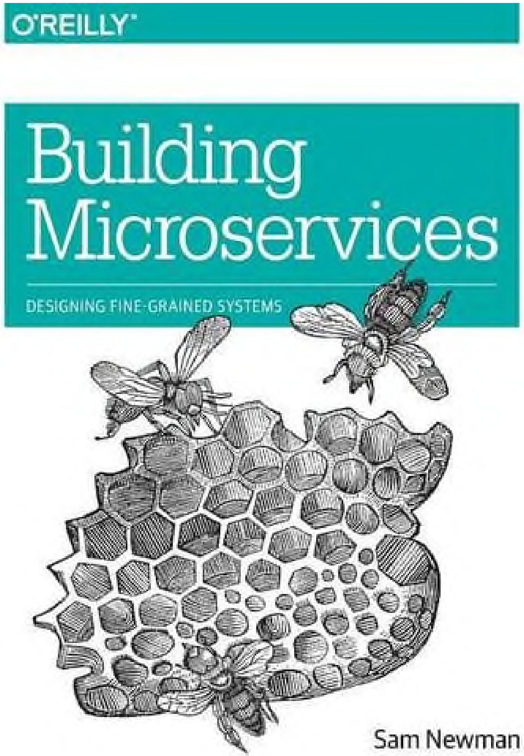
http://www.vinaysahni.com/best-practices-for-building-a-microservice-architecture

Recommendations

Architecture Recommendations for Microservices

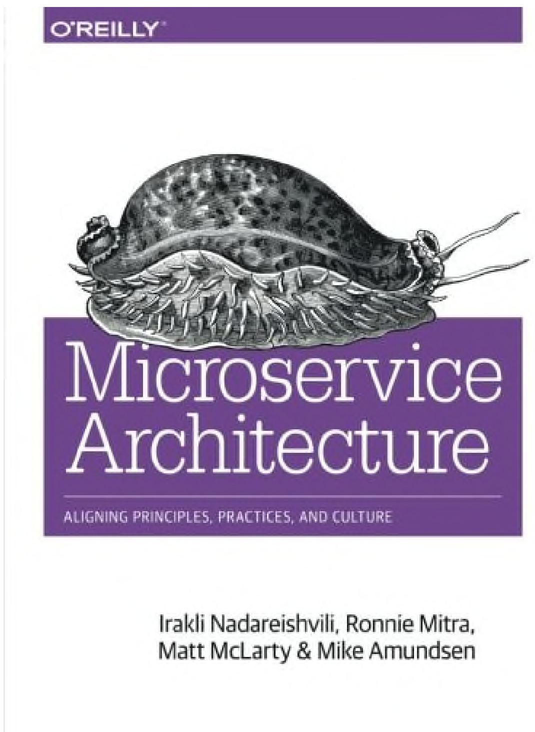
1. Use microservices only if they fit into the *overall architecture* and strategy (enterprise strategy)
2. Respect all *architecture principles* while building and evolving microservices
3. Establish a working governance structure for microservices
4. Base microservices on the *domain model* (domain driven engineering)
5. *Automate* the management/deployment of microservices and the integration infrastructure

Textbook



Sam Newman:
Building Microservices
O'Reilly and Associates, USA, 2015. ISBN 978-1-491-95035-7

Textbook



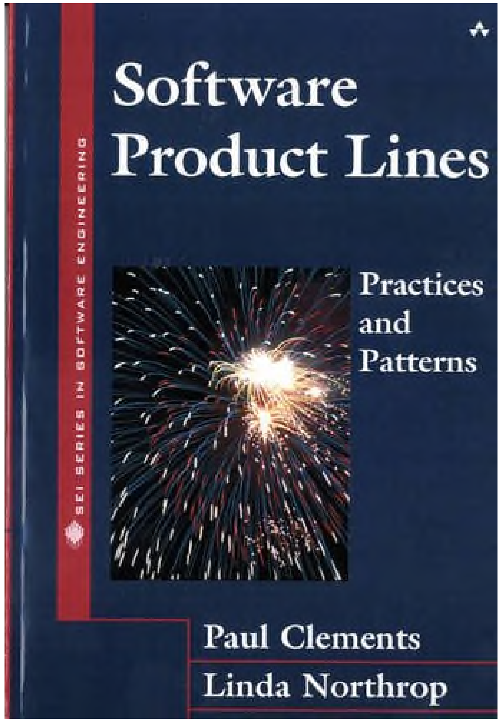
Mike Amundsen, Matt Mclarty:
Microservice Architecture – *Aligning Principles, Practices, and Culture*
O'Reilly Media, Inc, USA, 2016. ISBN 978-1-491-95625-0

Recommendations

Software Product Lines

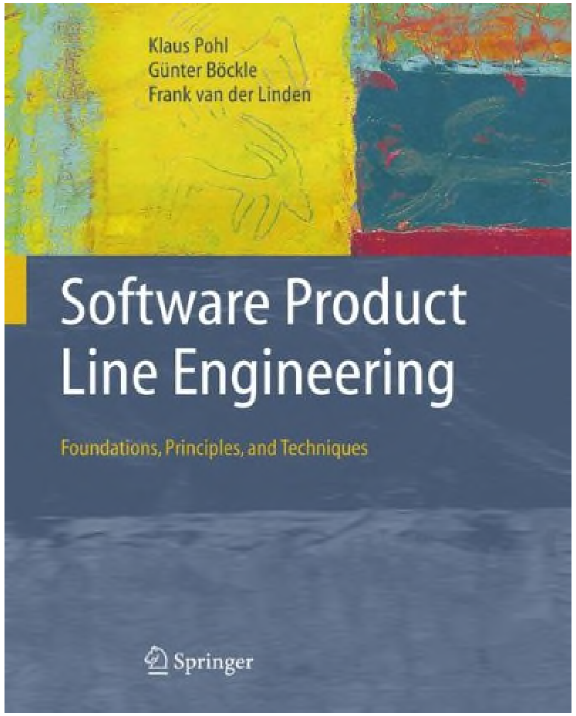
1. Product lines make use of planned, massive reuse
2. The product line approach promises significant advantages in development cost, time-to-market and quality of the products = strong amplifier for agility)
3. Product line engineering requires specific organizational structures and a new software development process
4. The product line approach is a mature, proven technology which leads to considerable competitive advantages for companies

Textbook



Paul Clements, Linda Northrop:
Software Product Lines – *Practices and Patterns*
Addison Wesley Inc., USA, 2015. ISBN 978-0-134-42408-8

Textbook



Klaus Pohl, Gunter Bockle, Frank J. Linden:
Software Product Line Engineering – *Foundations, Principles and Techniques*
Springer-Verlag, Berlin, 2010. ISBN 978-3-642-06364-0

Part 3 C