# Architecting Digital Ecosystems

March 16, 2023

The Fifteenth International Conference on Evolving Internet
INTERNET 2023
March 13, 2023 to March 17, 2023 - Barcelona, Spain

IARIA

**Prof.dr. Bedir Tekinerdogan**

Wageningen University & Research
Chair Information Technology
Wageningen, The Netherlands

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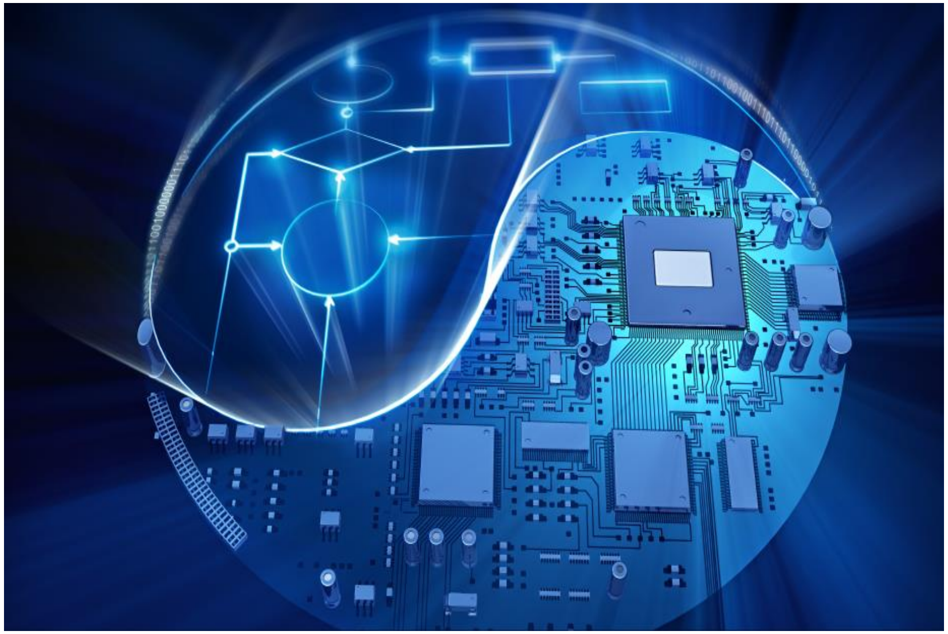
https://linkedin.com/in/bedir
https://www.researchgate.net/profile/Bedir-Tekinerdogan

WAGENINGEN UNIVERSITY & RESEARCH | 100years 1918 — 2018



# Background

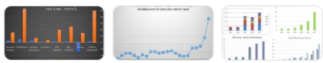
**In World's Top 2% Scientists ranking list**

## Experience

**Wageningen UR (University & Research centre)**
Full-time · 7 yrs 11 mos

**Full Professor and Chair Information Technology**
Jan 2015 - Present · 7 yrs 11 mos
Wageningen, The Netherlands

I am the chairholder of the Information Technology Group, which now consists of 15 staff members, 5 Post-docs, and more than 20 PhD candidates. I am responsible for managing and leading the group wit ...see more



**Full Professor and Chair Business Science Section**
Dec 2021 - Present · 1 yr
Wageningen, Gelderland, Netherlands

Besides my role as chair of the Information Technology group, I also serve as the chair of the Business Science section at Wageningen University & Research. The section consists of five strong chair groups incl ...see more

Section Business Science (SBS)

**Management Team Member - 4TU.NIRICT**
4TU.Federation
2017 - Present · 5 yrs 11 mos

4TU.NIRICT
4TU.NIRICT is the Netherlands Institute for Research on ICT and comprises all ICT research of the universities of technology in the Netherlands. It is one of the centers of the 4TU...

**Faculty Professor**
Bilkent University
Sep 2008 - Dec 2014 · 6 yrs 4 mos
Ankara, Turkey

- received rank of Associate Professor from the Turkish Inter-University Council (2010)
- IBM Faculty Award nomination (2009, 2010) ...see more

**Assistant Professor**
University of Twente
Aug 2003 - Sep 2008 · 5 yrs 2 mos

My research and education activities were focused on software architecture and related topics including aspect-oriented software architecture design, software architecture modeling, software architectur ...see more

**Visiting Assistant Professor**
Bilkent University
Sep 2002 - Jul 2003 · 11 mos

This was a kind of a sabbatical leave for me. At Bilkent University I have introduced and given the courses Software Architecture Design (2), Aspect-Oriented Software Development, and the course Object- ...see more

Show all 9 experiences →

## Education

**University of Twente**
PhD, Computer Science/ Software Engineering
1995 - 2000

PhD Thesis: Synthesis-Based Software Architecture Design

**University of Twente**
MSc, Computer Science - Software Engineering
1989 - 1994

MSc Thesis: The Design of an Object-Oriented Framework for Atomic Transactions

**Isala College, Silvolde, The Netherlands**
High School (Academic Stream)
1982 - 1988

Atheneum-DiplomaUitreiking.jpg
1988 - Isala College High School Graduation Ceremony

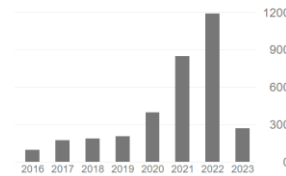
**Primary School "De Dobbelsteen", Ulft, The Netherlands**
1976 - 1982


Google Scholar

Bedir Tekinerdogan
Professor of Information Technology, Wageningen University, The Netherlands
Verified email at wur.nl - Homepage
Software Engineering Information Technology Systems Engineering System-of-Systems Artificial Intelligence and D...

Cited by VIEW ALL

| | All | Since 2018 |
|---|---|---|
| Citations | 5353 | 3129 |
| h-index | 38 | 28 |
| i10-index | 128 | 69 |




ELSEVIER

Bedir Tekinerdogan Edit
Prof.Dr. · Chair at Wageningen University & Research
Netherlands | Website
Current activity

| | |
|---|---|
| Research Interest Score | 3,333 |
| Citations | 4,128 |
| h-index | 33 |

Citations over time

Profile Research (334) Stats Following Saved list Add research

View your latest weekly report

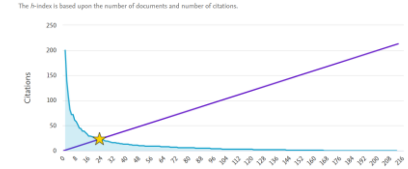
Overall publications stats

| 3,333 | 180,629 | 4,128 | 627 | 56 |
|---|---|---|---|---|
| Research Interest Score | Reads | Citations | Recommendations | Mentions |
| +18.3 last week | +879 last week | +17 last week | +6 last week | → --- |

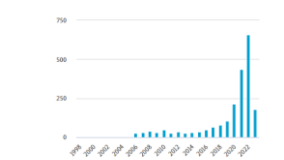
Scopus

This author's h-index 23

The h-index is based upon the number of documents and number of citations.

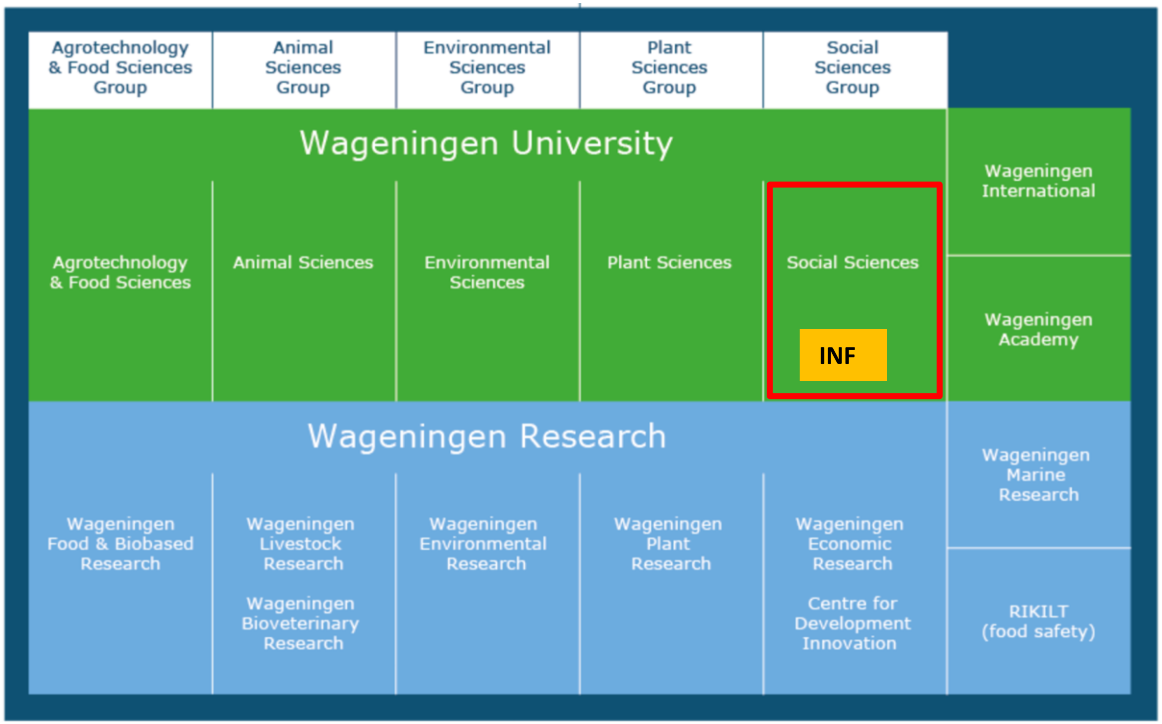



Citations 2,137



# Wageningen University & Research

- Focus on *life sciences,* which comprises the branches of science that involve the scientific study of **living organisms**,
- like plants, animals, and human beings.


# INF – 2023 ….

## Chair

**prof.dr.ir. B (Bedir) Tekinerdogan**
Professor

## Research and Teaching Staff

dr. T (Tarek) Alskaif
Assistant Professor

C (Cagatay) Catal
Externe medewerker

prof.dr.ir. GJ (Gert Jan) Hofstede
Personal Professor Artificial Sociality

dr.ir. A (Ayalew) Kassahun

drs. MR (Mark) Kramer
Assistant Professor

dr. Q (Qingzhi) Liu
Assistant Professor

ir. G (Gerard) Moerland
Developer Digital Learning Material / Lecturer

dr. SA (Sjoukje) Osinga
Assistant Professor

dr. JR (Joao) Pereira Valente
Assistant Professor

dr. CN (Cor) Verdouw
Researcher

ir. MA (Maarten) Zijp
Docent

dr. KE (Kwabena) Bennin
Universitair docent

dr. WSK (Will) Hurst MSc BSc
Assistant Professor in Data Science

ir. N (Natasja) Ariesen
Lecturer

dr. Ö (Önder) Babur
Assistant Professor

dr. Y (Yara) Khaluf
Assistant Professor

MD (Dogu) Cengiz
Functioneel (Informatie) beheerder

M (Maria Del Mar) Ariza Sentís MSc
Onderwijs-/Onderz...

S (Sander) Breevaart BSc
Docent

To be hired
Assistant Professor

To be hired
Lecturer

## Postdocs

G (Giulia) Salvini
DLO Onderzoeker

dr. S (Serdar) Demirel
Onderzoeker

dr. A (Abide) Coskun-Setirek
Postdoctoral Researcher

R (Romina) Rodela PhD
Externe medewerker

dr. S (Sergio) Velez Martin
Onderzoeker

To be hired

To be hired

## PhD Candidates

HG (Havva) Gürbüz MSc
Promovendus

C (Cigdem) Avci
PhD Candidate (external), Promovendus

JF (Fred) Goede
Onbekend , Promovendus

DR (Dilli) Paudel MSc
Promovendus

ir. HJM (Joep) Tummers
PhD Candidate

C (Christos) Pylianidis
Promovendus

PE (Paulina) Rosero Añazco
PhD candidate

MN (Margaret) Githinji

E (Erkinai) Derkenbaeva MA
Promovendus , Promovendus

C (Chenglong) Zhang
Promovendus

G (Gonzalo) Mier Muñoz
Promovendus , Promovendus

LZH (Laura) Jansen MSc
PhD candidate

M (Matthew) Ayamga MSc
Promovendus , Promovendus

NNK (Ngakan) Krisnawijaya MSc
Promovendus

GE (Ece) Eksi
Promovendus

M (Mingzhu) Du MSc
Promovendus

C (Christa) Blokhuis MSc
Promovendus , Promovendus

Z (Zhen) Cao Msc
Promovendus

To be hired

To be hired

To be hired

## Deputy Administrator / Secretary

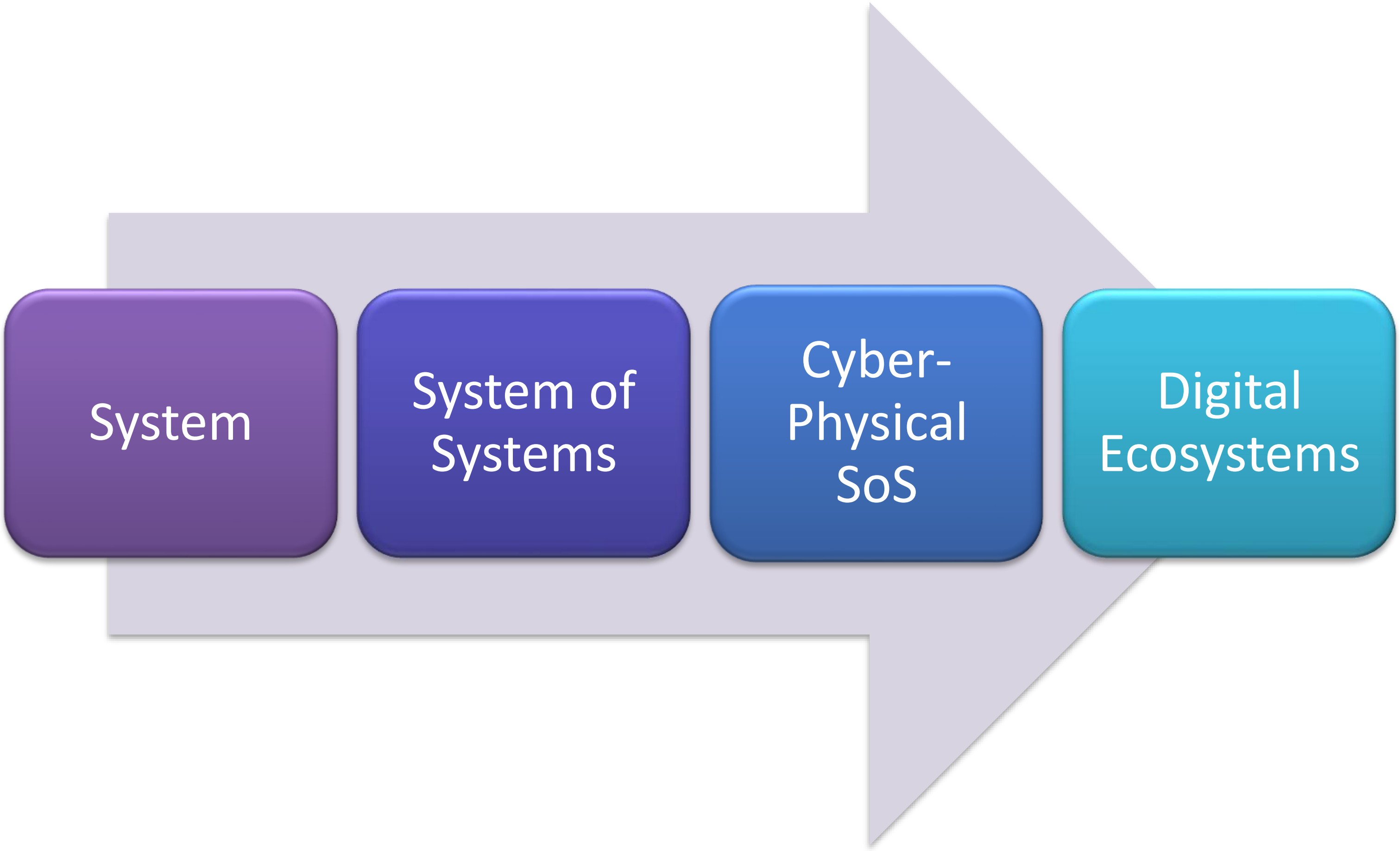
CH (Claudia) Ravestein
Secretary

MCJ (Marieke) Möller-de Haas
Secretary

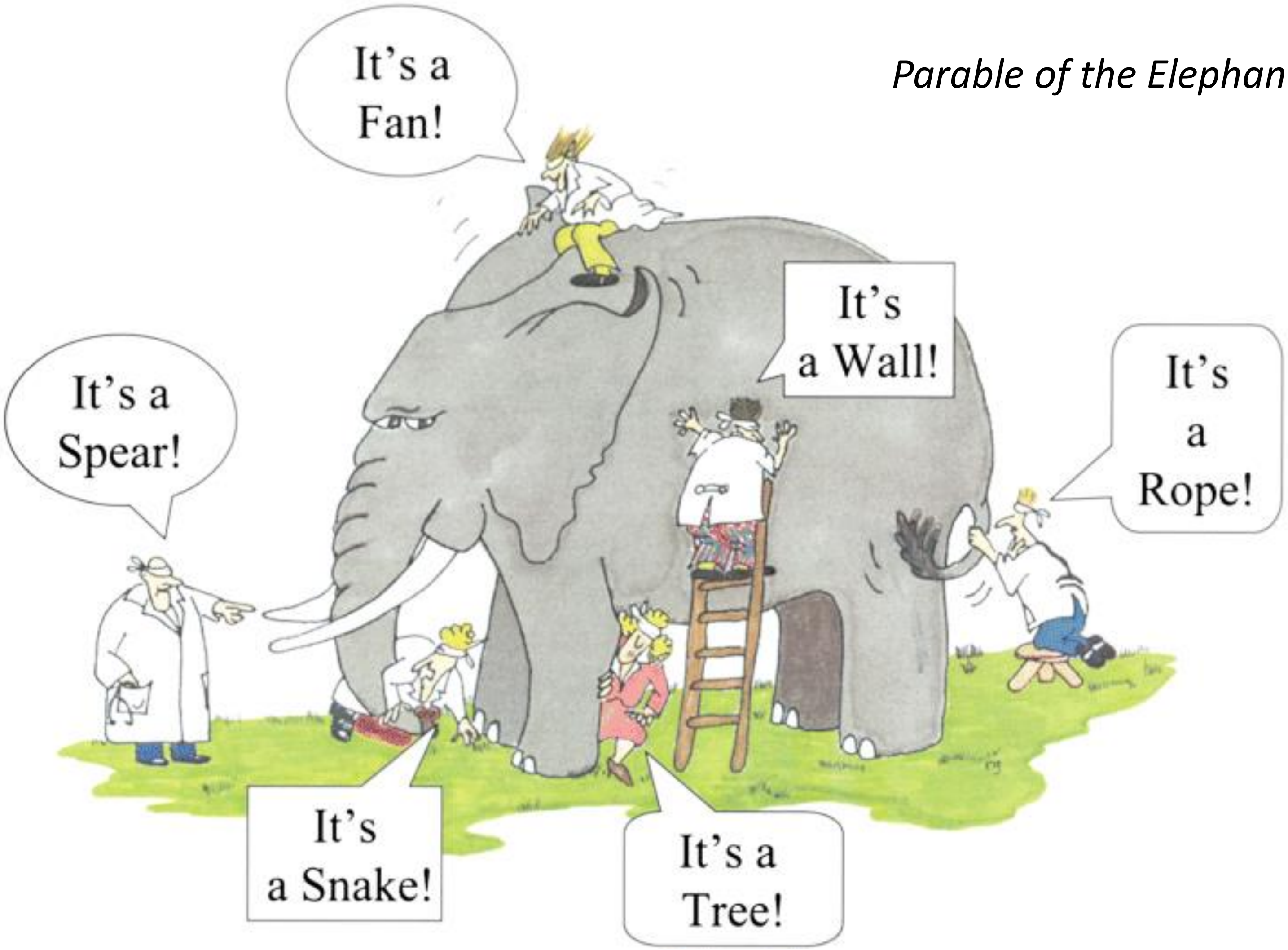
L (Laura) Simon
Deputy Administrator

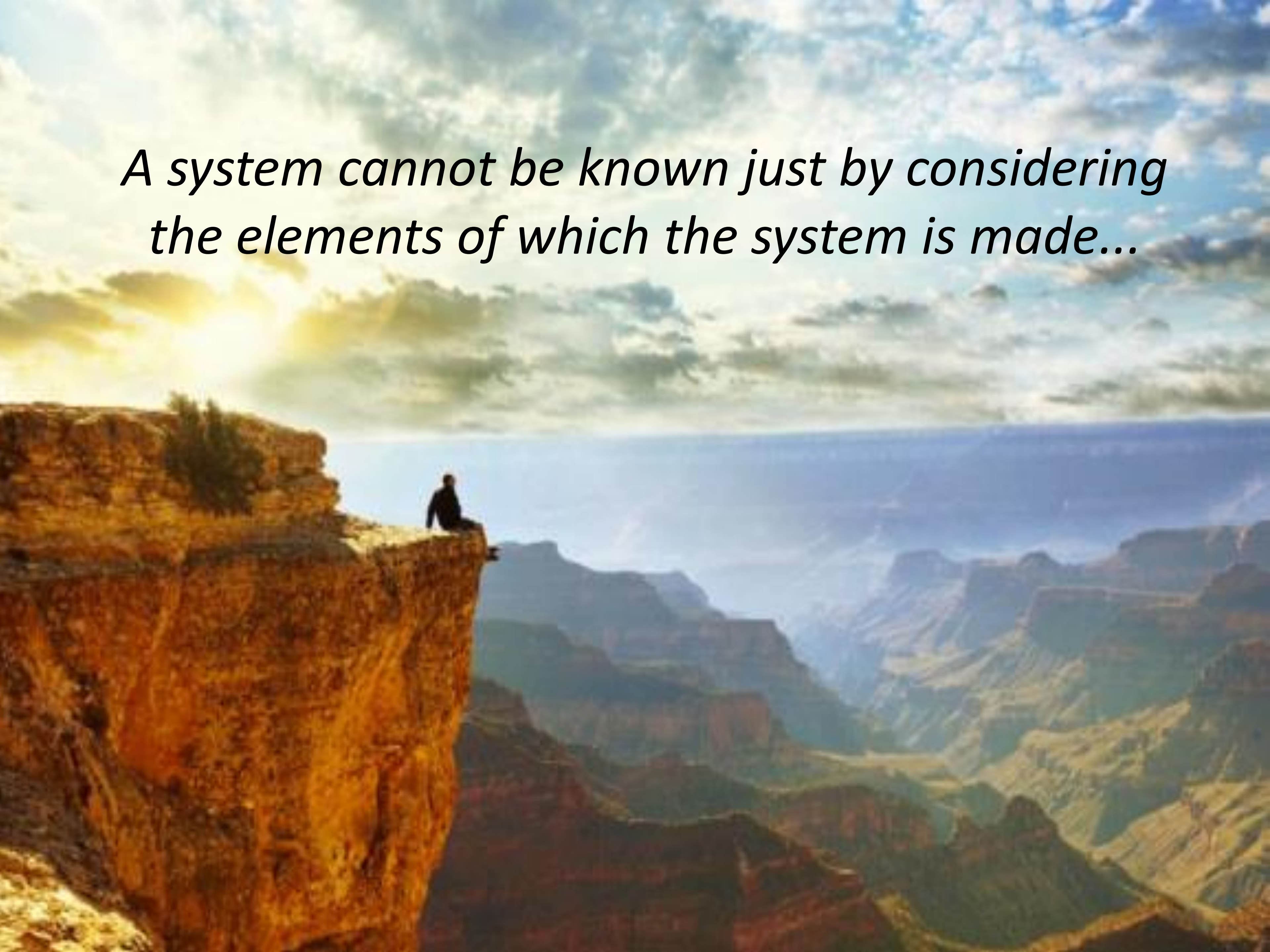
### Information Technology

Our mission is to advance the state-of-the-art of smart systems and system of systems engineering to support innovations in the life sciences application domains. Hereby, we focus on software engineering, data science, and socio-technical systems engineering.


System
System of Systems
Cyber-Physical SoS
Digital Ecosystems

*Parable of the Elephant*




*A system cannot be known just by considering the elements of which the system is made...*

# System?

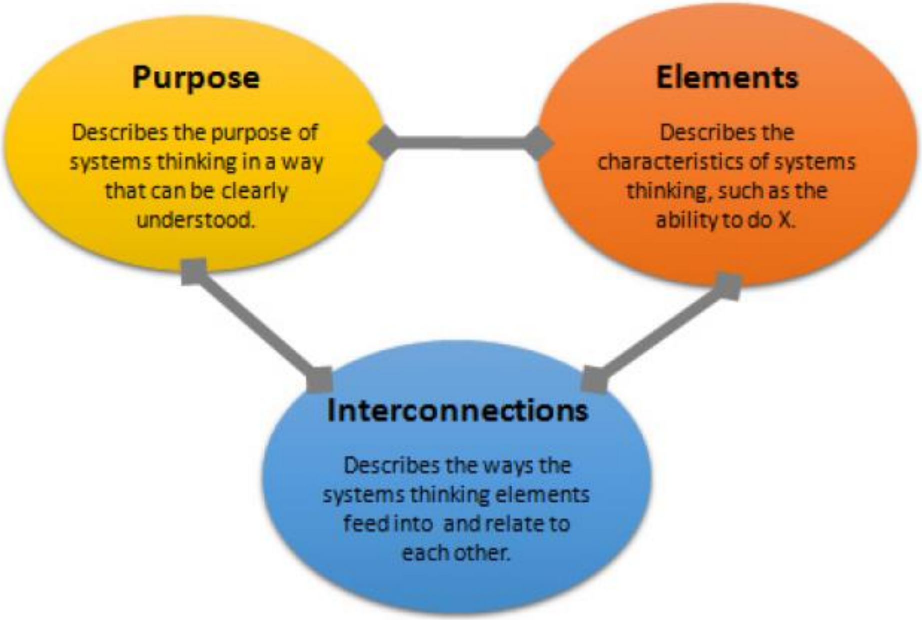
# System – Definition

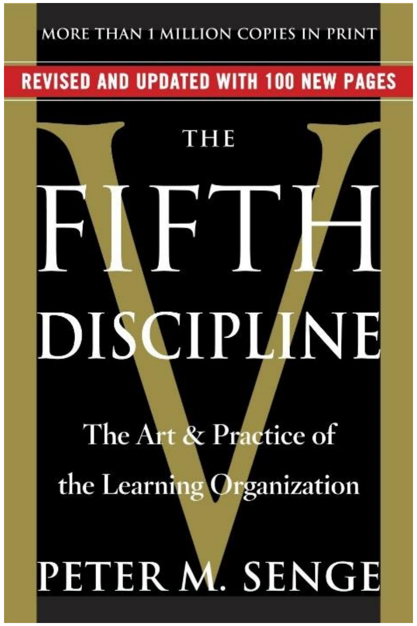
- "A system is a set of **interacting** or **interdependent** components forming an **integrated whole**".
  - Wikipedia

- "A set of things **working together** as parts of a mechanism or an **interconnecting network**."
  - Oxford dictionary

- an entity which maintains its existence through the **mutual interaction of its parts**.
  - www.systems-thinking.org

*"Systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots" - Peter Senge*

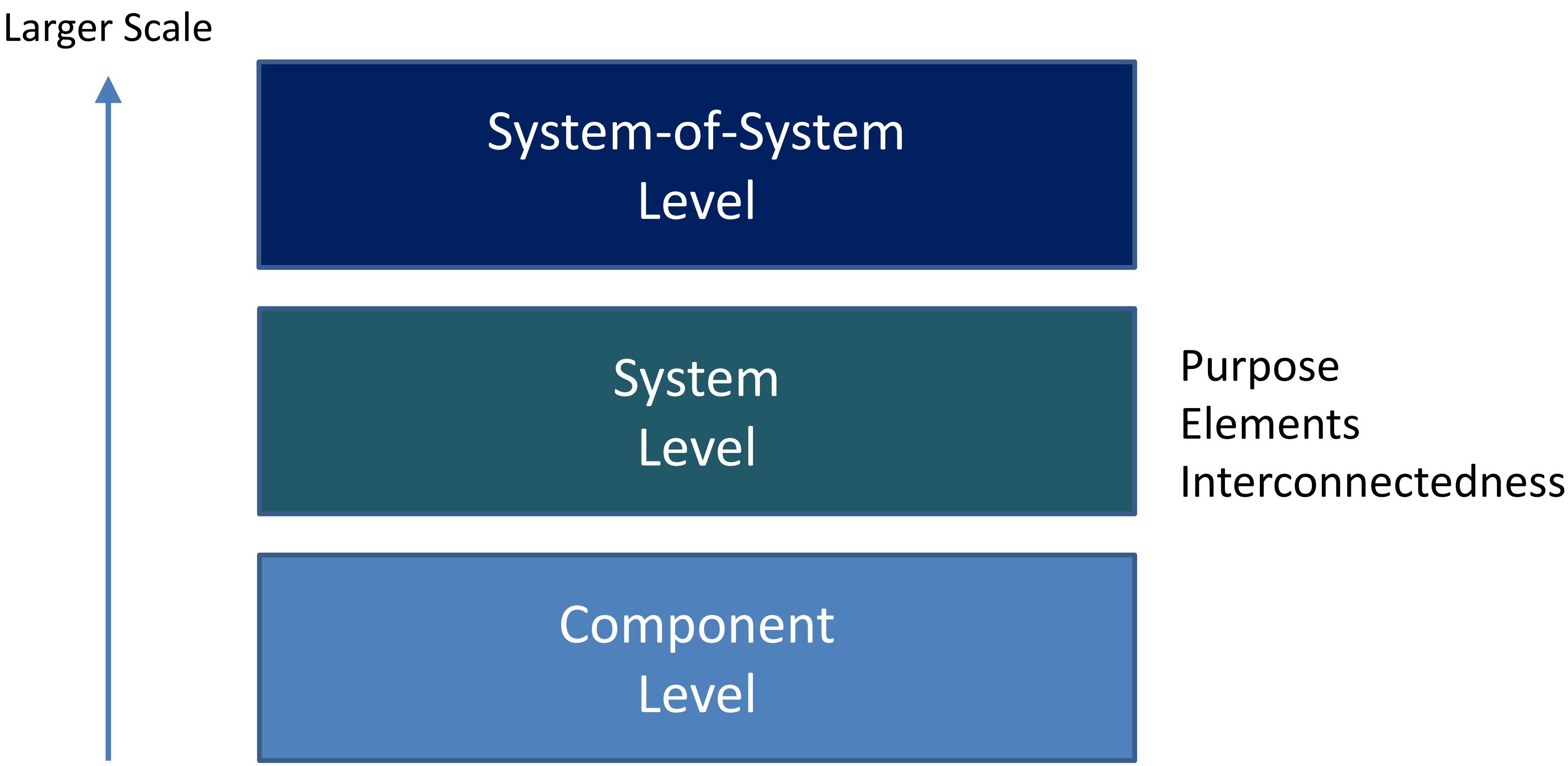



Ross D. Arnold, Jon P. Wade. A Definition of Systems Thinking: A Systems Approach, Procedia Computer Science 44 ( 2015 ) 669 – 678.

# System of Systems

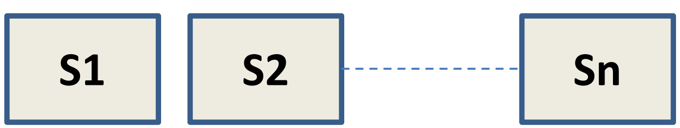
# System Scale

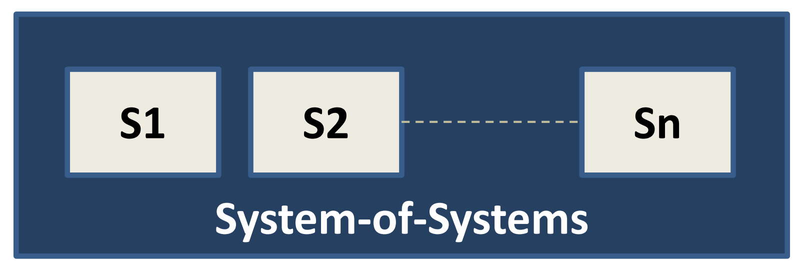


# System-of-Systems

- A system-of-systems is defined as a set or **arrangement of systems** that results when **independent** and useful **systems are integrated** into a larger system that delivers **unique capabilities**

N capabilities



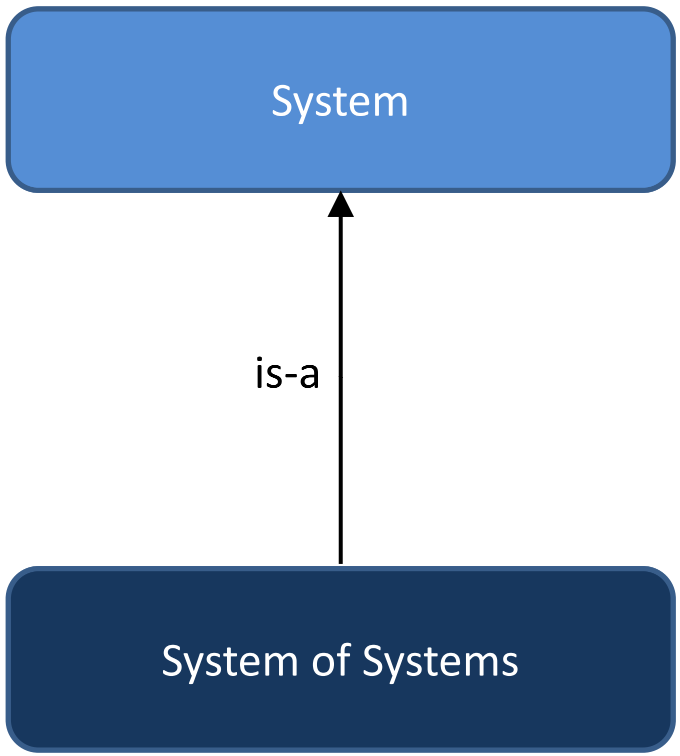

> N capabilities

*more than the sum of its parts*

# System-of-Systems Characteristics

- **Operational independence** of constituent systems
- **Managerial independence** of constituent systems
- **Emergent behaviour** as a result of the interacting constituent systems in the wider whole
- **Evolutionary development** of the SoS
- **Geographical distribution** of the constituent systems

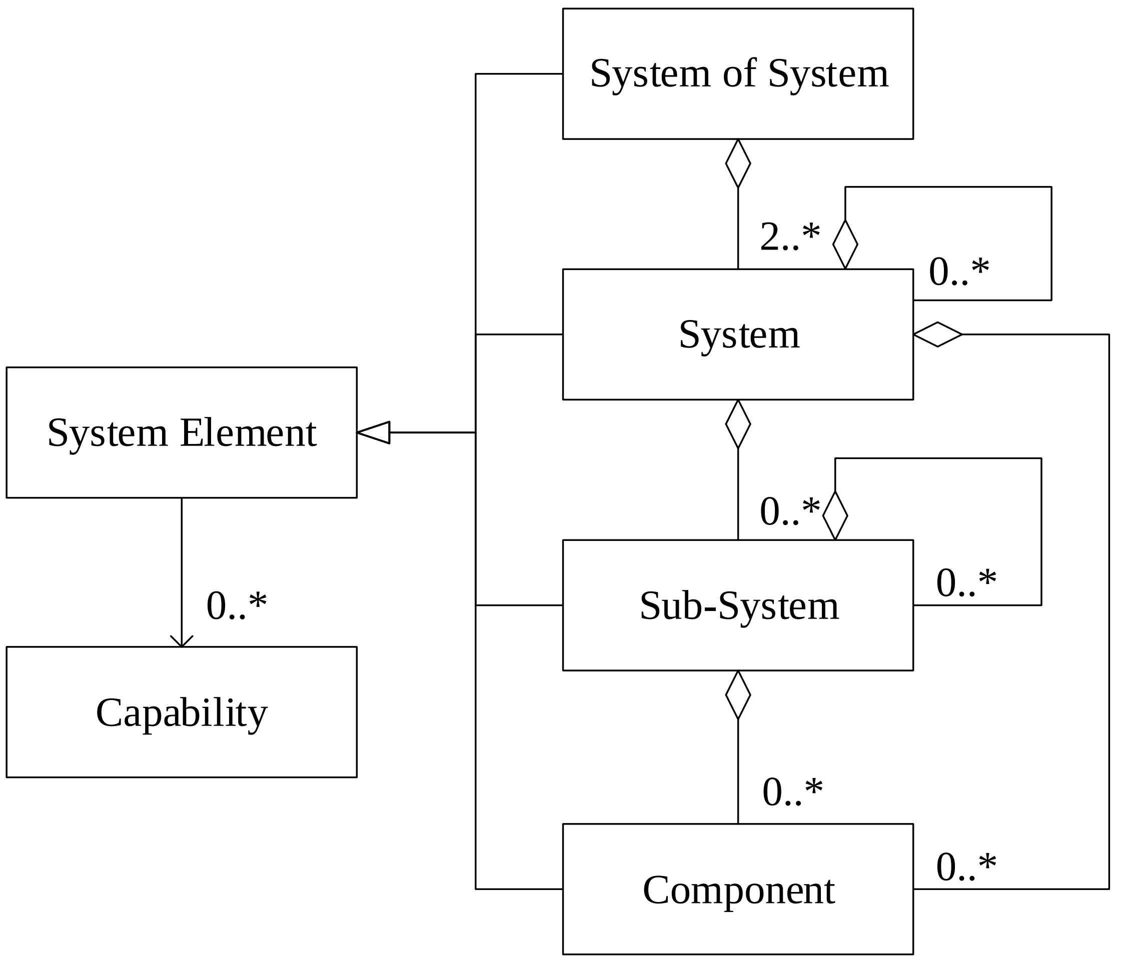
# System, System of Systems




Purpose
Elements
Interconnectedness

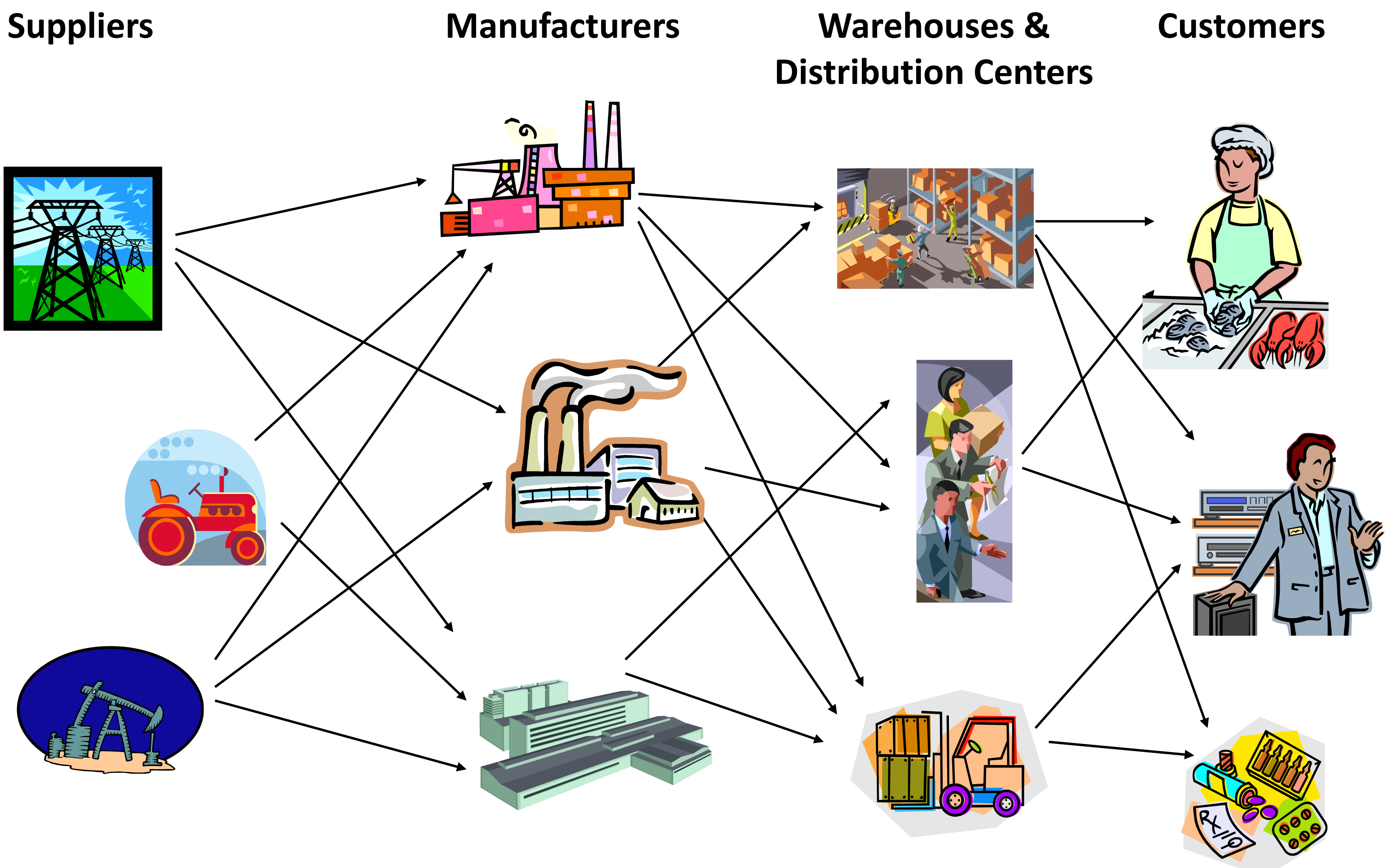
Operational independence
Managerial independence
Emergent behavior
Evolutionary development
Geographical distribution

# SoS- Logical Configuration

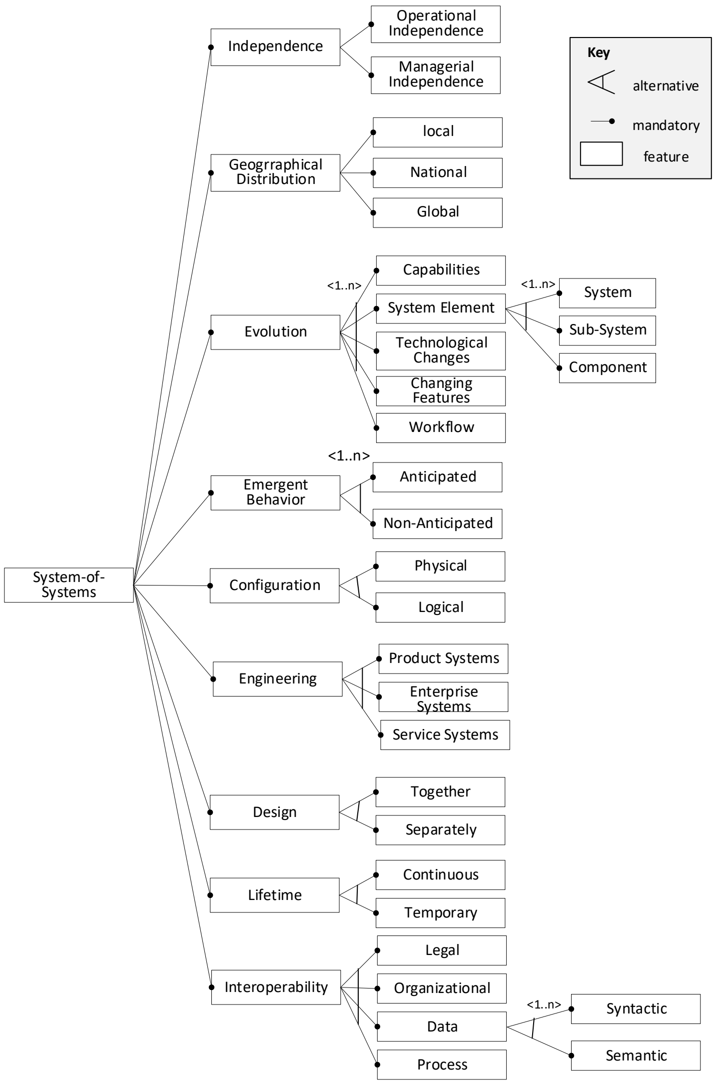



# Social System


# Logistics Management/Supply Chains



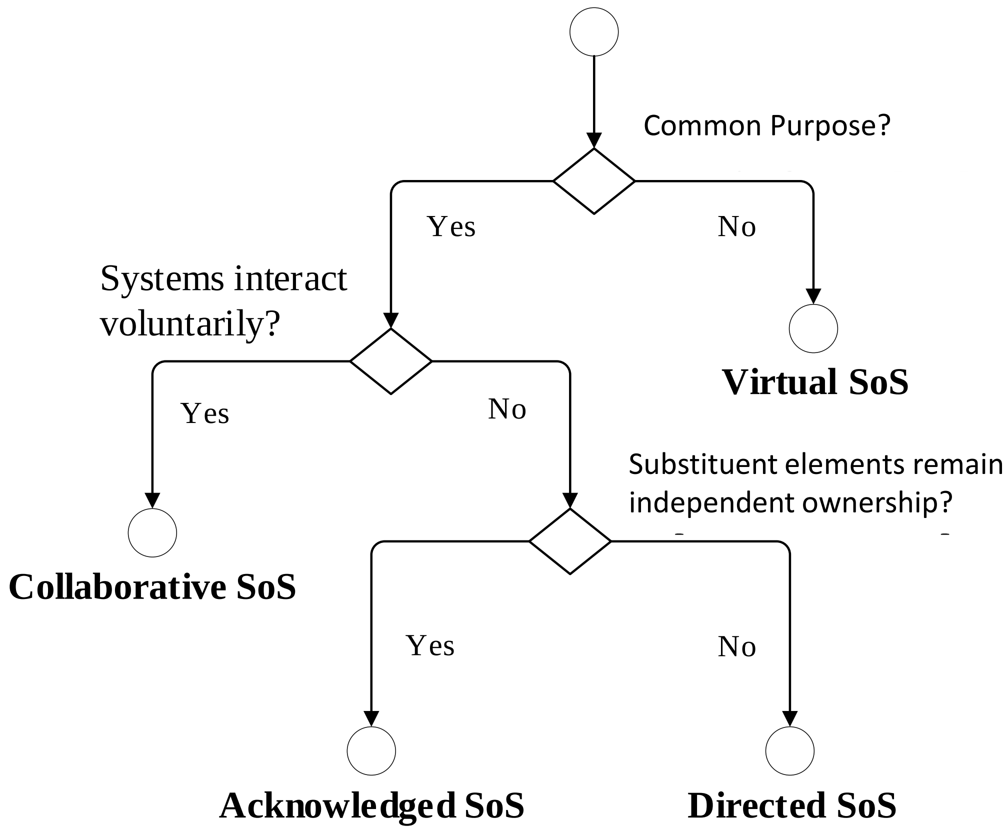
# System of Systems - Examples




| System | System-of-Systems |
|---|---|
| ***Technological*** | |
| Airplane | Air Traffic Control System |
| Car, Road | Integrated Traffic System |
| Train | Rail Network |
| Smart Metering, Wind Turbine | Smart Grid |
| Computer | Distributed System |
| Farm | Integrated Precision Farming System |
| Building | Town, Shopping Mall |
| ***Social*** | |
| Town Council | Government, United Nations, European Union |
| Family, Social Group | Town, Nation |
| Student, Teacher, School | Education System |
| Company | Enterprise, Stock Market |
| ***Natural*** | |
| Animal | Herd |
| Plant | Forest |
| Weather, RI | Eco-system |
| Star | Solar System |

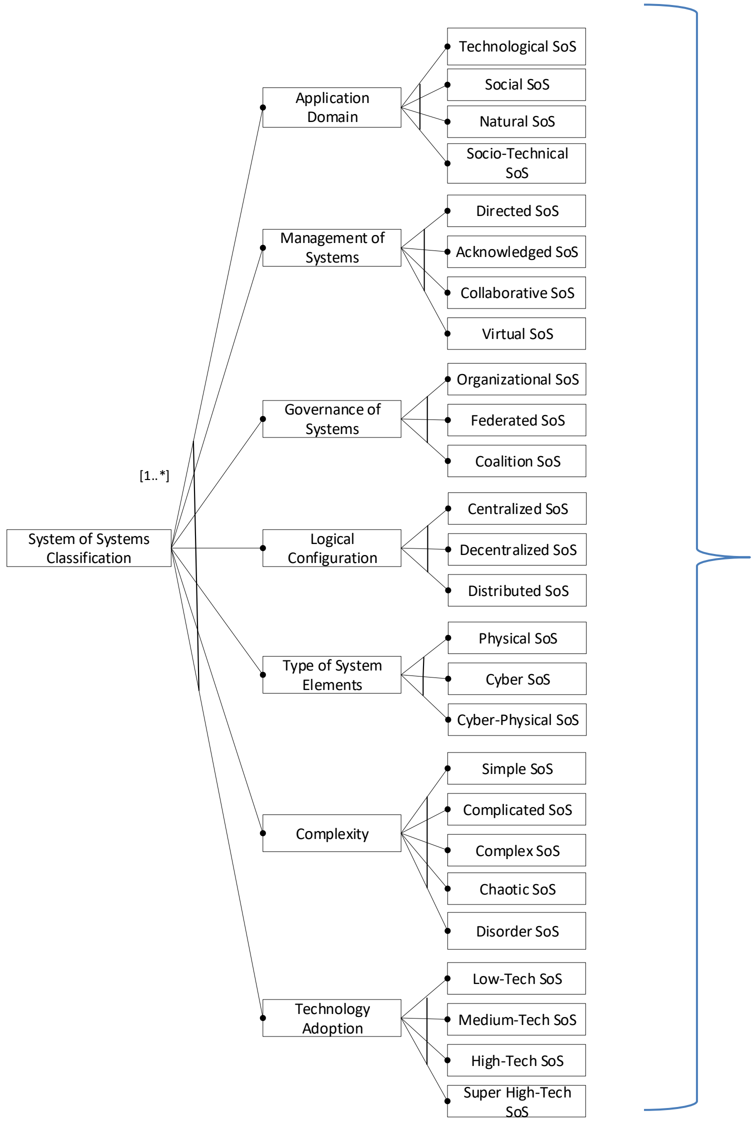
B. Tekinerdogan, "Multi-Dimensional Classification of System-of-Systems," *2019 14th Annual Conference System of Systems Engineering (SoSE)*, 2019, pp. 278-283, doi: 10.1109/SYSOSE.2019.8753841.

# SoS Classification based on Management Criteria




B. Tekinerdogan. Engineering Connected Intelligence: A Socio-Technical Perspective. Wageningen University, 2017

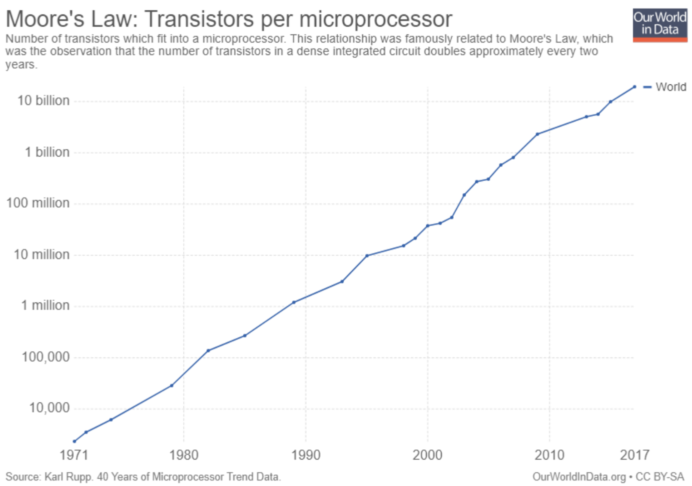
# Multi-Dimensional Classification of SoS

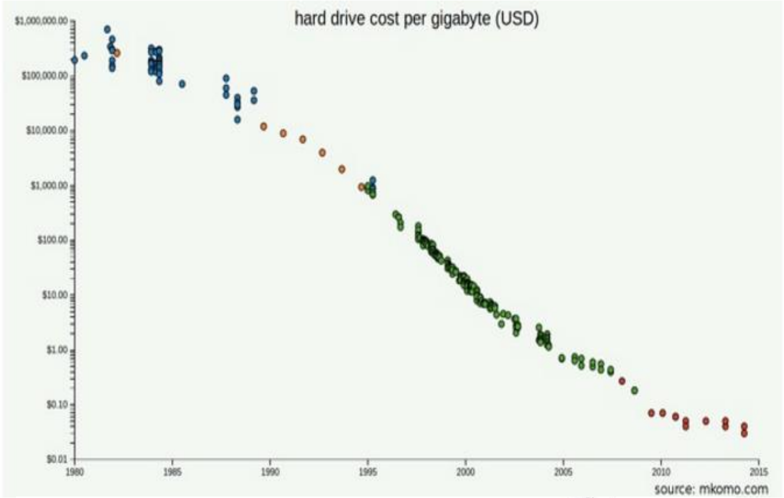


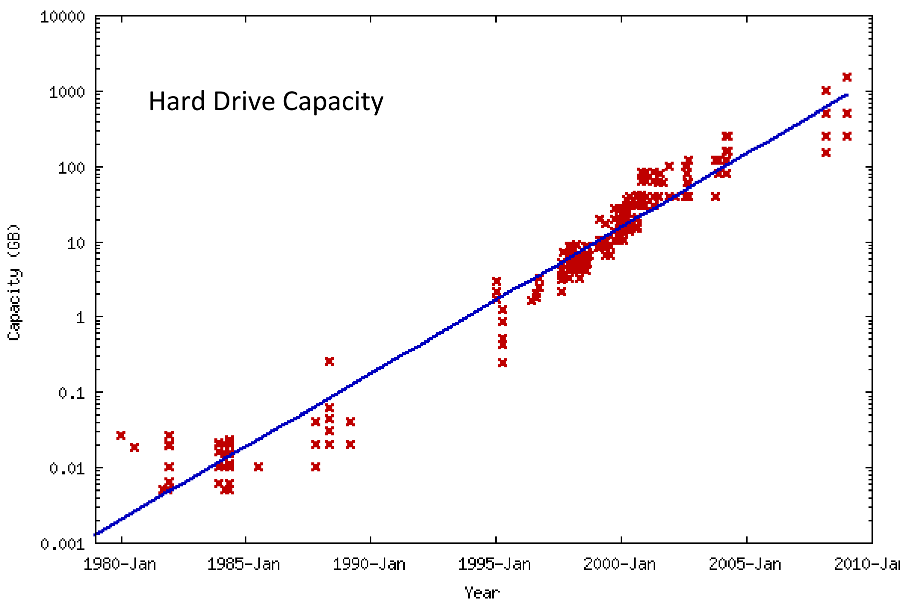


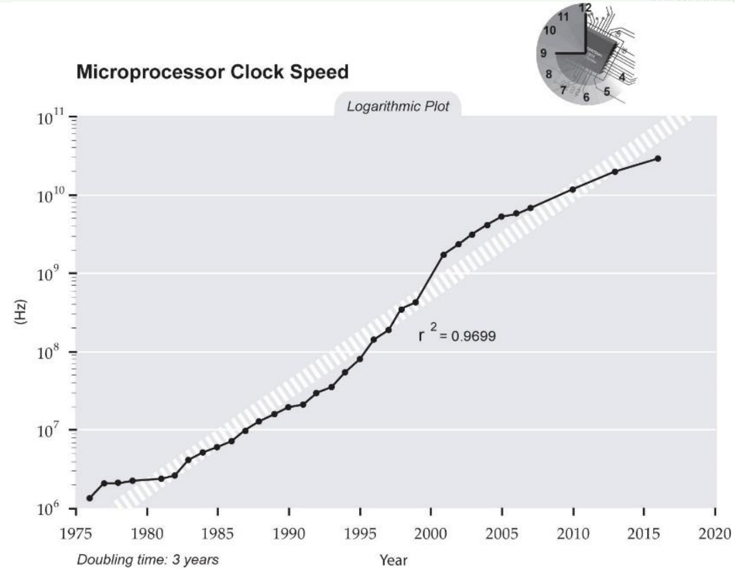
B. Tekinerdogan, "Multi-Dimensional Classification of System-of-Systems," *2019 14th Annual Conference System of Systems Engineering (SoSE)*, 2019, pp. 278-283, doi: 10.1109/SYSOSE.2019.8753841.

# Computing - Stronger, Faster, Cheaper…

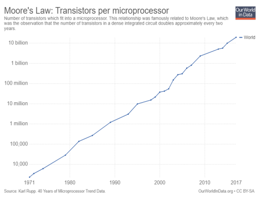


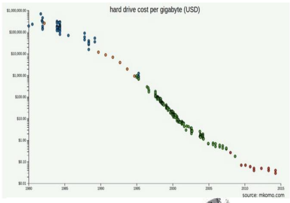



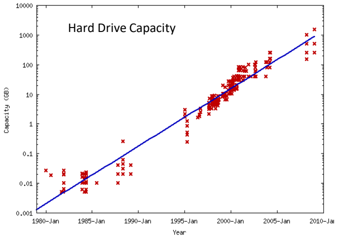



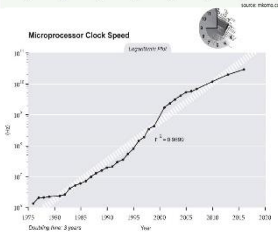



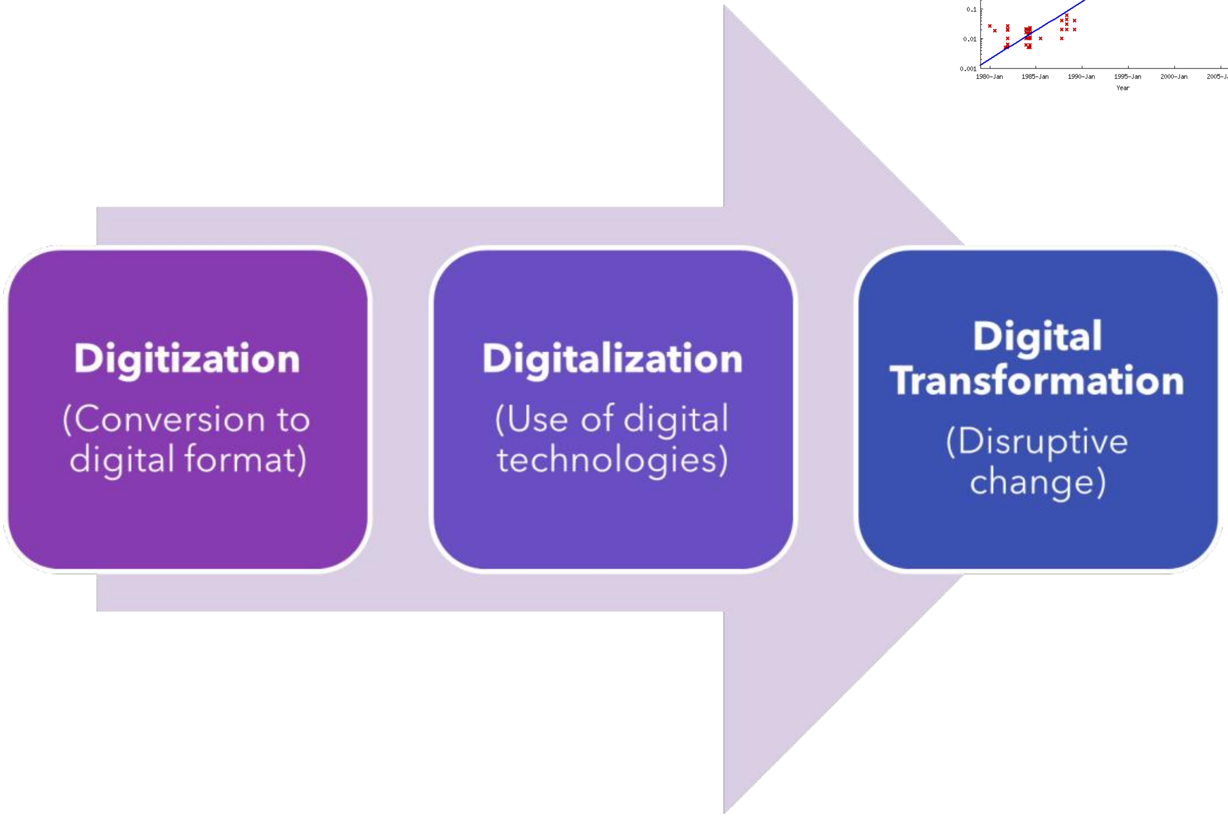
# Digitization, Digitalization, Digital Transformation



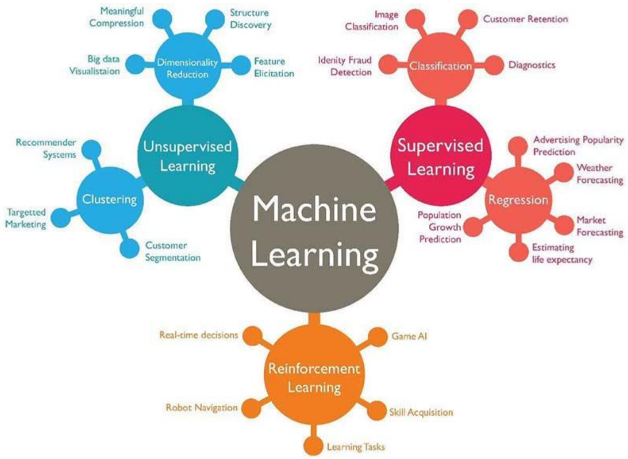



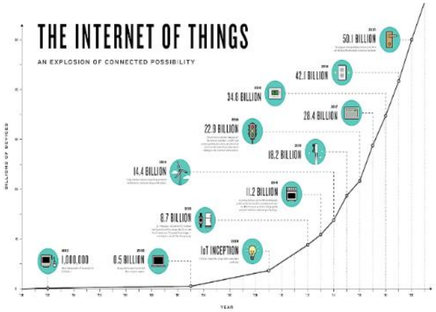



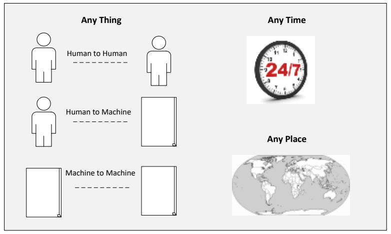

https://www.linkedin.com/pulse/digitalization-past-present-future-bedir-tekinerdogan/

# Pervasive Computing



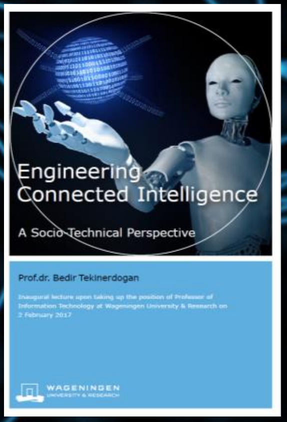


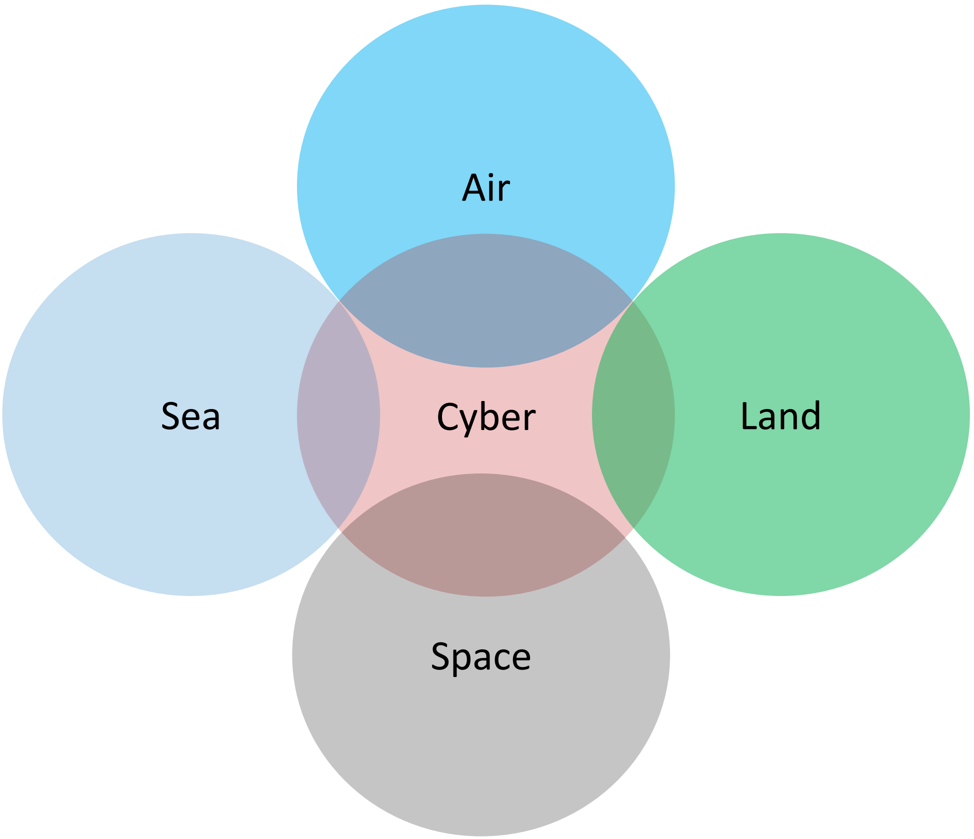

**Big Data**

# Systems get Smarter, and Connected

B. Tekinerdogan. Engineering Connected Intelligence: A Socio-Technical Perspective, Wageningen University, isbn 978-94-6343-049, doi 10.18174/401115, 2017

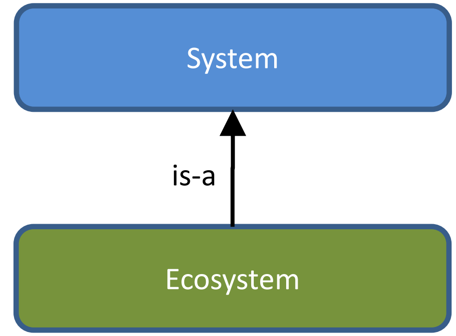


# Physical Space and,...Cyberspace



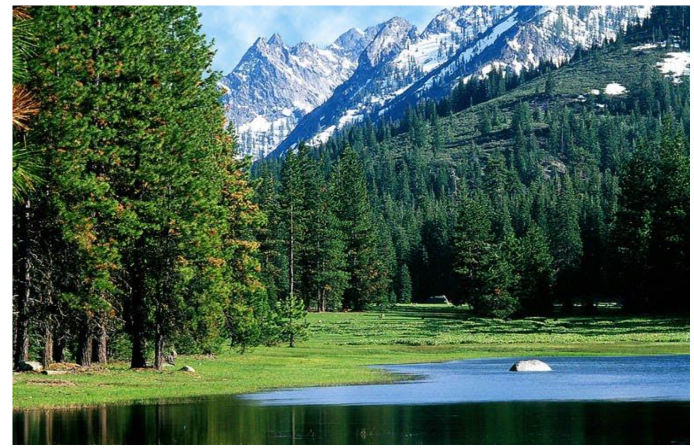

# Cyber-Physical System of Systems

# Ecosystem…




- Ecosystem or Ecological System is a **community of living organisms** in conjunction **with the physical environment interacting as a system**.
- These biotic and abiotic components are regarded as linked together through nutrient cycles and energy flows.
- they can be of any size but usually encompass specific, limited spaces.

*Symbiosis*
(sýn, "together", bíōsis, "living" is any type of a close and long-term biological interaction between biological organisms)



# Ecosystem - Characterisics

- **Biodiversity**: An ecosystem is composed of a wide variety of living organisms that interact with each other and with their environment.
- **Energy flow**: Ecosystems rely on a continuous flow of energy, usually from the sun, to sustain the life of its organisms.
- **Nutrient cycling**: Ecosystems also rely on the cycling of nutrients to maintain the health of the community.
- **Adaptation**: Ecosystems are constantly changing and adapting to their environment.
- **Interdependence**: The organisms within an ecosystem are interdependent on one another for survival. The loss of one species can have a significant impact on the entire ecosystem.
- **Self-regulation**: Ecosystems have the ability to self-regulate and maintain balance through feedback mechanisms. This ensures that the ecosystem remains healthy and sustainable over time.

# Ecosystem - Relations

- **Predation**: This relationship involves one organism (the predator) killing and consuming another organism (the prey) for food. This relationship is common in many ecosystems and plays a critical role in maintaining balance and regulating populations.

- **Competition**: Competition occurs when two or more organisms require the same resources, such as food, water, or shelter. This can lead to a struggle for survival and often results in one organism outcompeting the other.

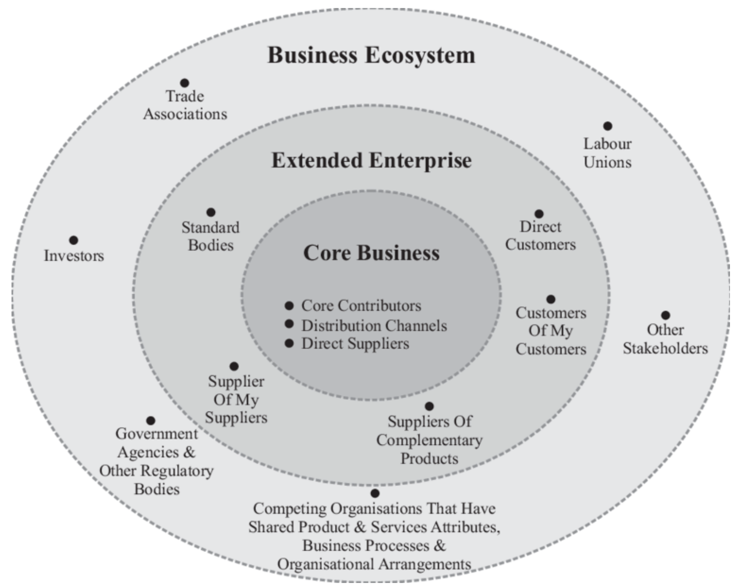
- **Symbiosis**: Symbiotic relationships occur when two or more organisms live together in a close and mutually beneficial relationship.

# Ecosystem – Symbiotic Relations

- **Mutualism**: Both organisms benefit from the relationship (++).
  - For example, bees and flowers have a mutualistic relationship where bees pollinate the flowers and the flowers provide the bees with nectar.
- **Commensalism**: One organism benefits from the relationship, while the other is neither helped nor harmed (+0)
  - For example, birds building nests in trees or using the branches to rest is a form of commensalism.
- **Parasitism**: One organism benefits from the relationship at the expense of the other (+-)
  - For example, ticks and fleas are parasites that feed on the blood of their host animals, which can lead to disease and other health problems.

# Business Ecosystem

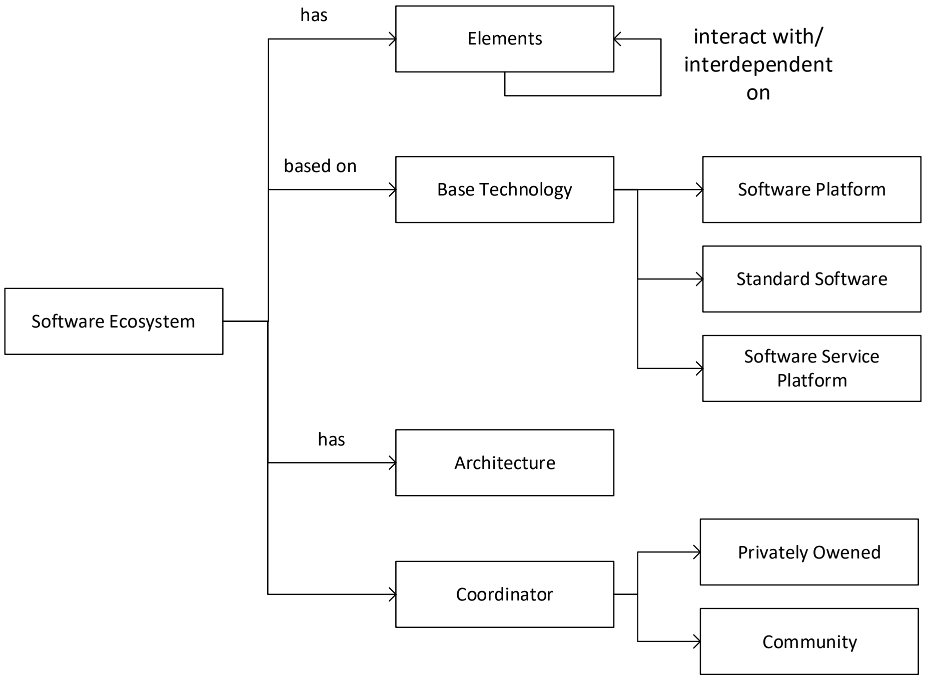
- a dynamic group of
- largely independent economic players
- that create products or services
- that together constitute a coherent solution




U. Pidun, M. Reeves, and M. Schüssler, Do you need a business Ecosystem?, Boston Consulting Group

# Digital Ecosystem

- A **digital ecosystem** refers to the **interconnected** network of digital devices, applications, and services that facilitate the creation, distribution, and consumption of digital content.
- This ecosystem involves the interaction between different digital technologies, software applications, and platforms, all of which work together to enable businesses and individuals to access, share, and use information in a digital format.



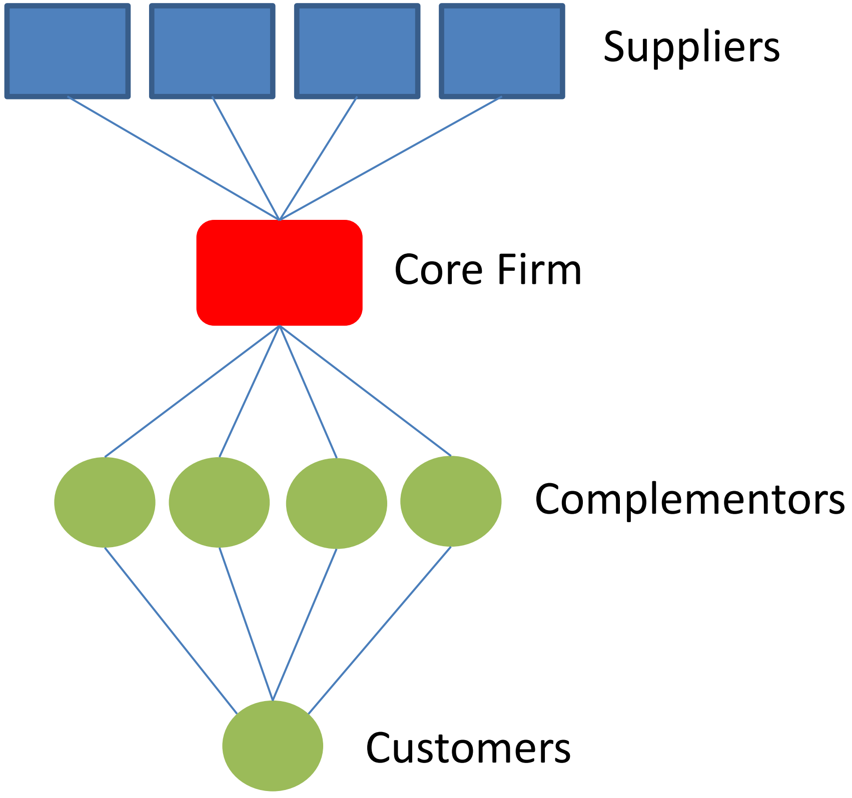
# Types of Business/Digital Ecosystem

- **Solution Ecosystem**: aims at creating a coherent solution. Core firm coordinates the innovation activities of the complementors, ensures continuous improvement of the overall product, and safeguards fair value sharing among ecosystem members
- **Transaction ecosystem**: A (digital) platform is used to integrate players in a two-sided market to establish an ecosystem.
- **Hybrid system**: The environment that combines features of a solution ecosystem with a transaction ecosystem.

# Solution Ecosystem

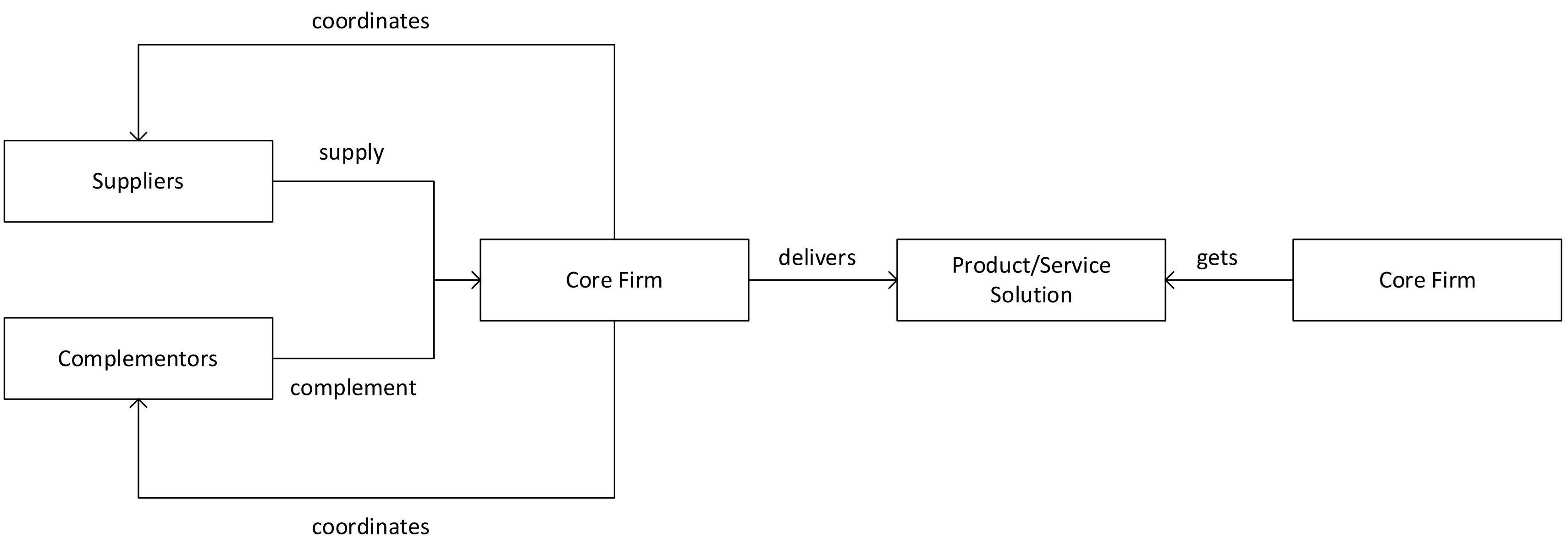
- has a core firm that orchestrates the offerings of several independent complementors

- Example:
  Smart home (key innovation) combining smart solutions (complementors) such as lighting, entertainment, and security products and services),

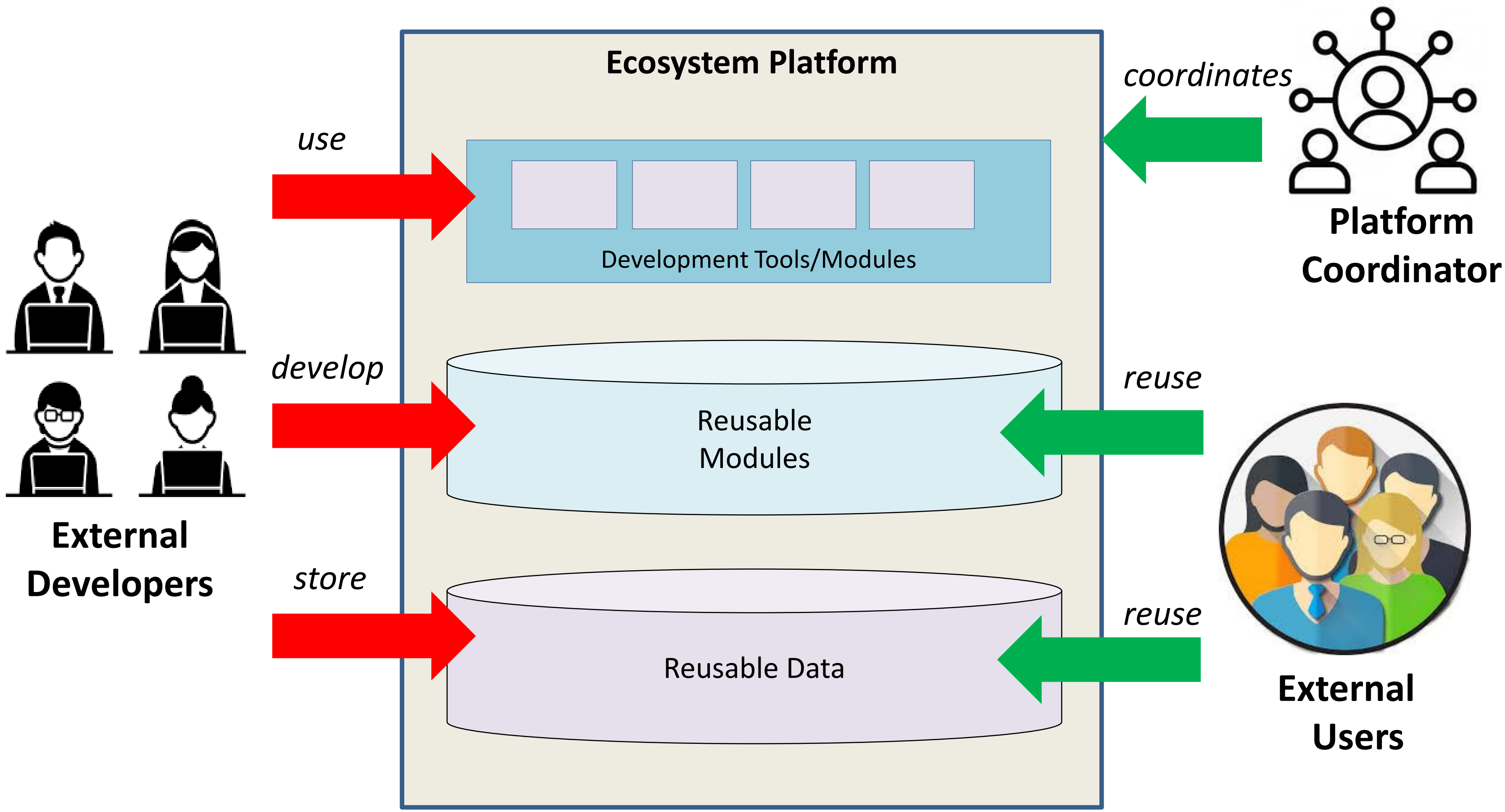



https://www.bcg.com/publications/2019/do-you-need-business-ecosystem

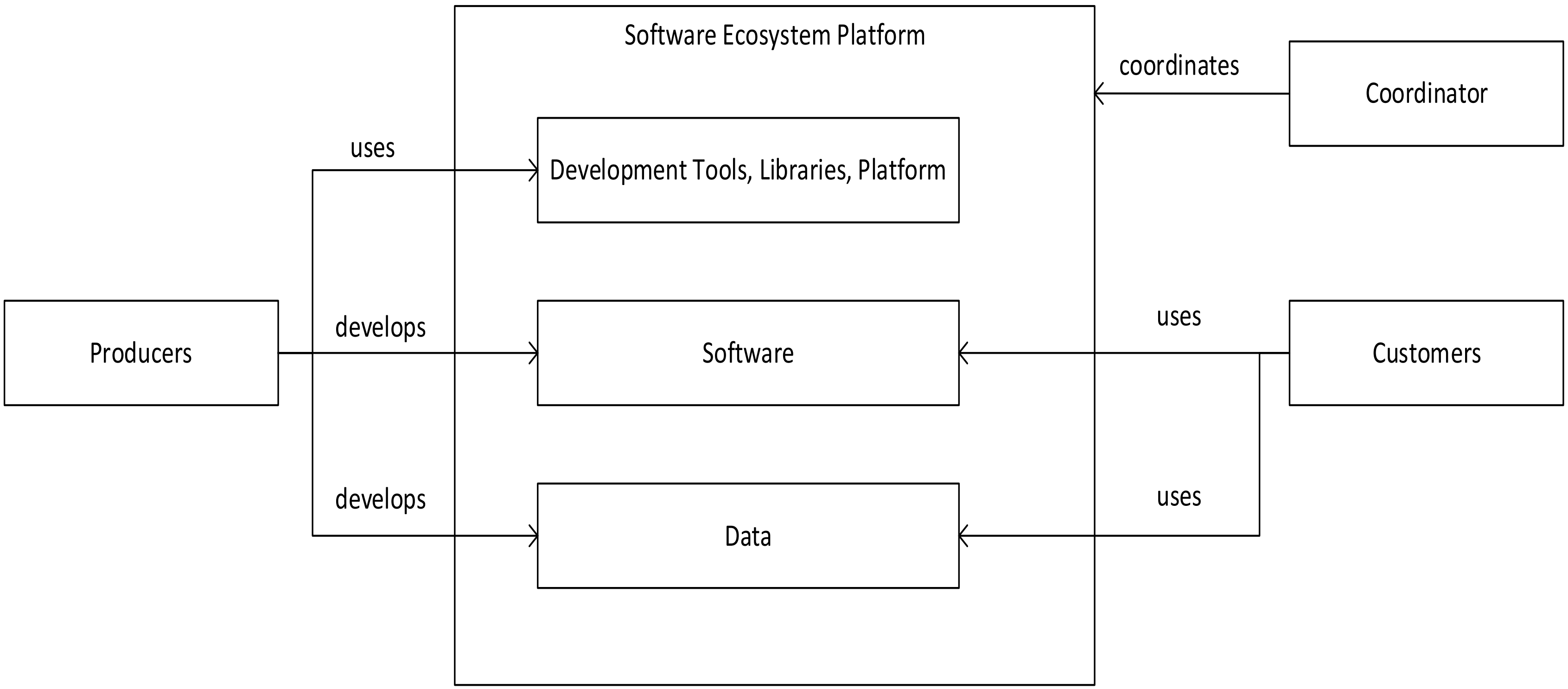
# Solution Ecosystem



# Platform-Based Ecosystem

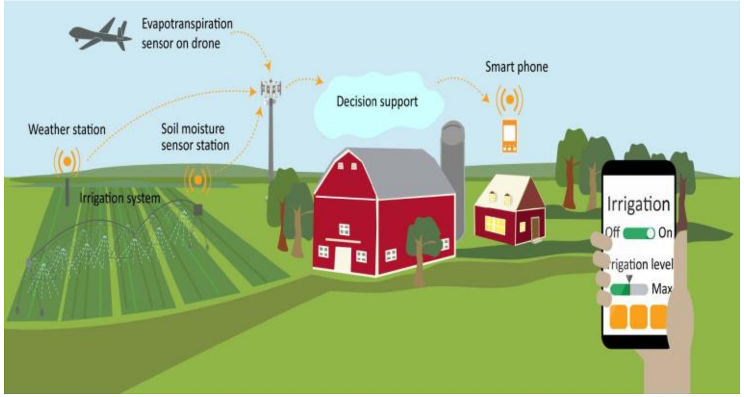


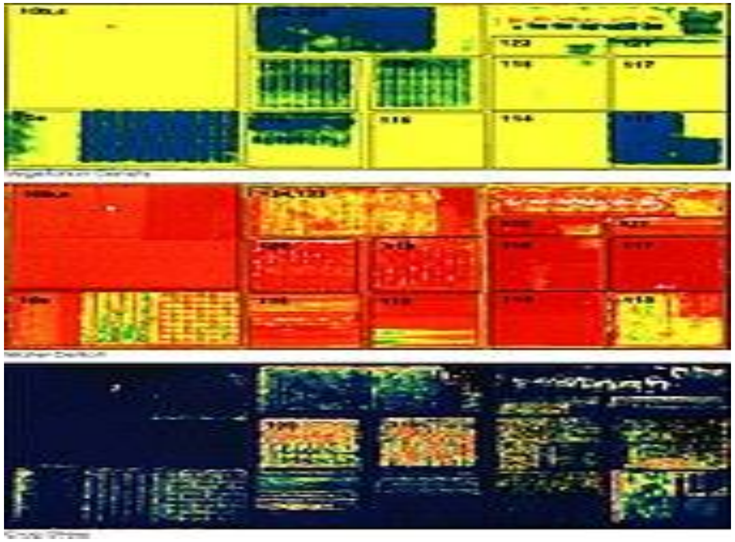
# Platform-Based Ecosystem



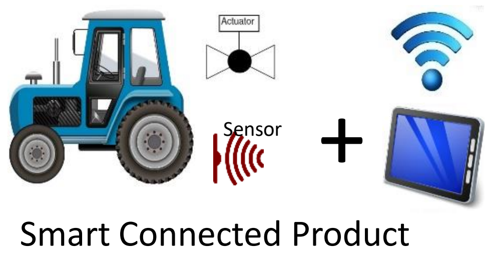
# Precision Farming

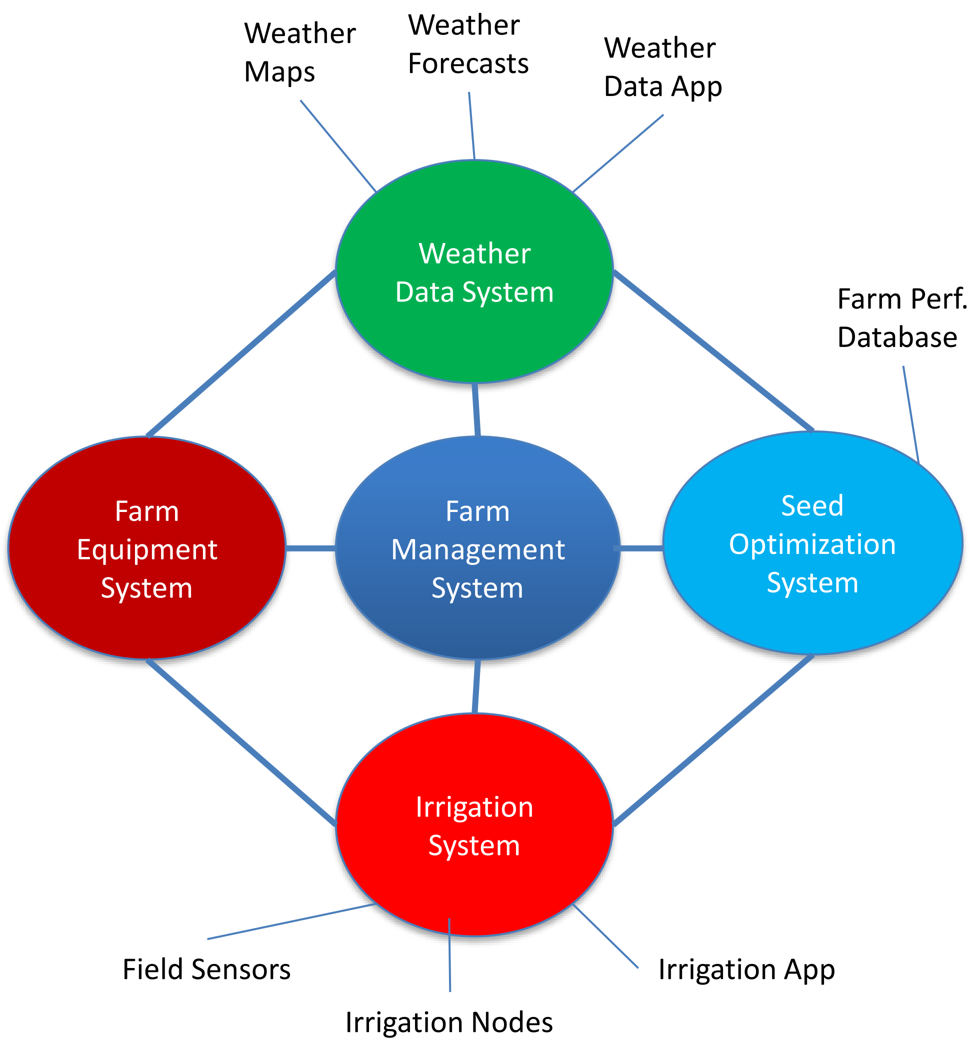
- Precision agriculture (PA) is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops.
- define a decision support system for whole farm management with the goal of optimizing returns on inputs while preserving resources.
- an application of advanced digital technologies
  - Robotics
  - Drones and UAV
  - Internet of Things
  - Cloud Computing
  - Machine Learning/Deep Learning
  - Software Engineering



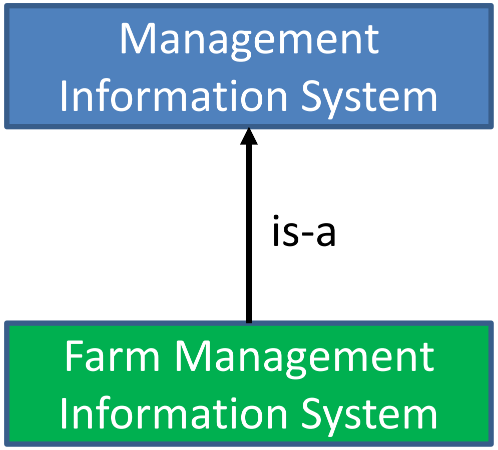
# Smart Farming System of System/Ecosystem



# Farm Management Information System

- **A key element of smart farming ecosystem**
- **Management information system (MIS)** is an information system used for decision-making, and for the coordination, control, analysis, and visualization of information in an organization.
- Involves people, processes and technology in an organizational context.
- the ultimate goal of the use of a management information system is to **increase the value and profits of the business**
- Farm management information systems (FMIS) is an MIS that supports the automation of data acquisition and processing, monitoring, planning, decision making, documenting, and **managing the farm operations**.



# Farm Management Information Systems/Ecosystem Publications

Computers and Electronics in Agriculture
Volume 157, February 2019, Pages 189-204

Review

## Obstacles and features of Farm Management Information Systems: A systematic literature review

J. Tummers, A. Kassahun, B. Tekinerdogan

Computers and Electronics in Agriculture
Volume 165, October 2019, 104939

Original papers

## Architecture framework of IoT-based food and farm systems: A multiple case study

Cor Verdouw [a, b], Harald Sundmaeker [c], Bedir Tekinerdogan [a], Davide Conzon [d], Teodoro Montanaro [d]

Springer Link

Open Access | Published: 11 December 2018

## Architecture design approach for IoT-based farm management information systems

Ö. Köksal & B. Tekinerdogan

Precision Agriculture 20, 926–958(2019) | Cite this article

Springer Link

Open Access | Published: 01 June 2020

## Reference architecture design for farm management information systems: a multi-case study approach

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Architecture Design Method for FMIS

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Open Access | Published: 01 June 2020

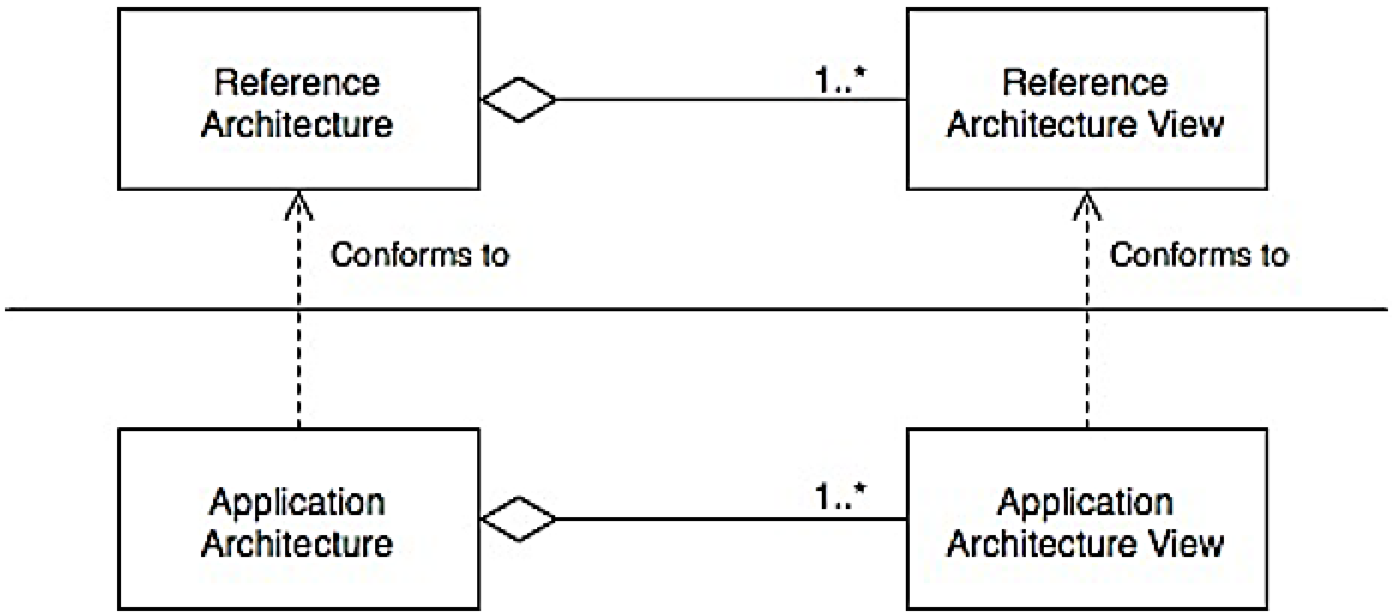
Reference architecture design for farm management information systems: a multi-case study approach

J. Tummers, A. Kassahun & B. Tekinerdogan

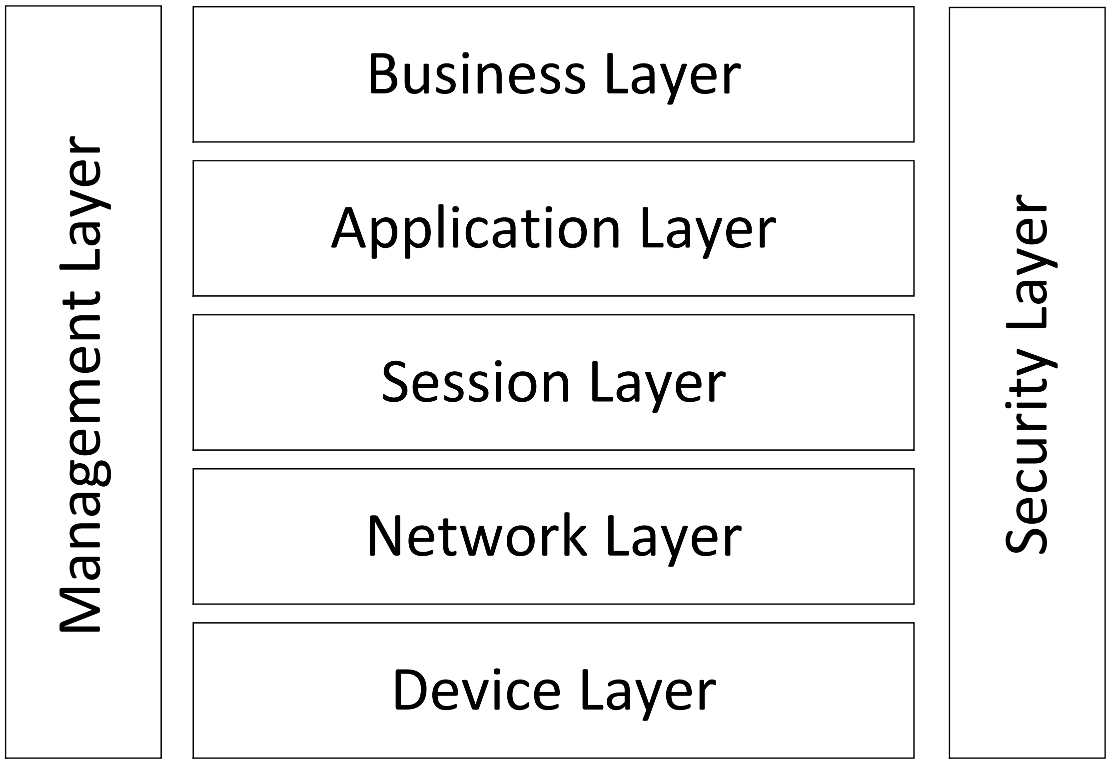
*Precision Agriculture* (2020) | Cite this article

FMIS Design

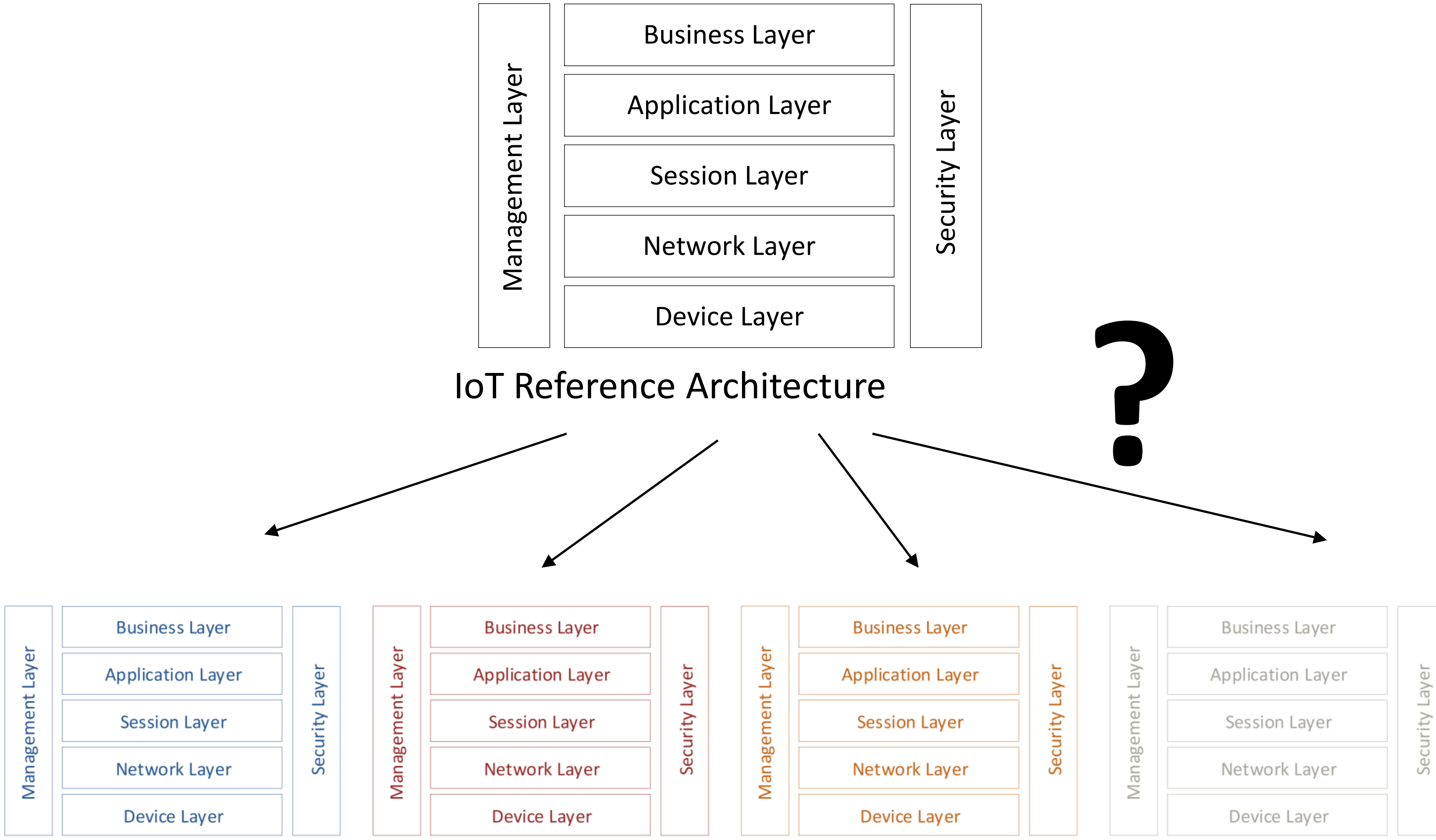
# Reference Architecture vs. Application Architecture



# IoT Reference Architecture



# Reference Architecture vs. Application Architecture



# IoT-based FMIS Architecture Design Approach

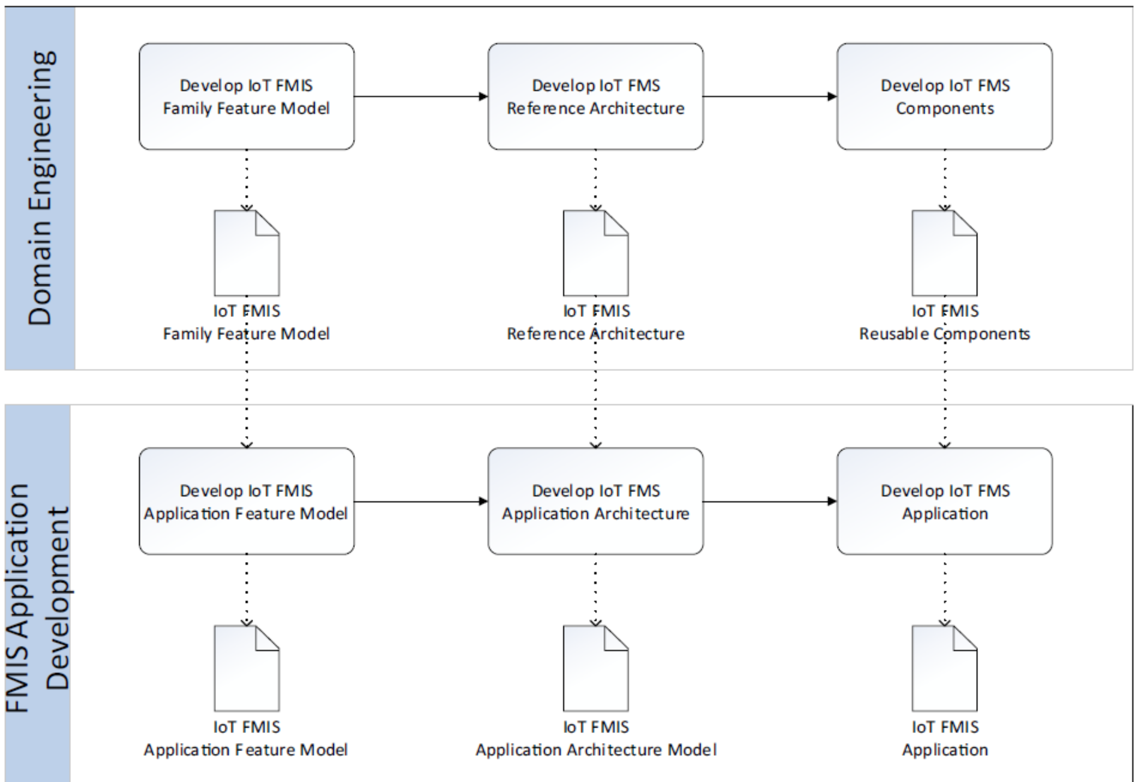
SpringerLink

Open Access | Published: 11 December 2018

Architecture design approach for IoT-based farm management information systems

Ö. Köksal & B. Tekinerdogan

*Precision Agriculture* **20**, 926–958(2019) | Cite this article

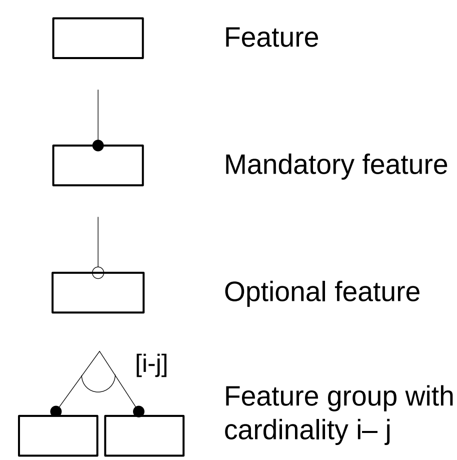


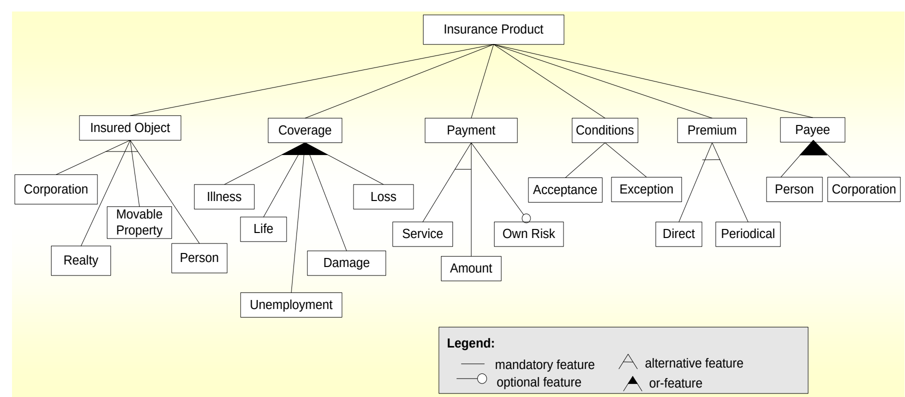
# Feature-Oriented Domain Modeling

- A **feature model** represents the common and the variable features of products and the dependencies between the variable features.

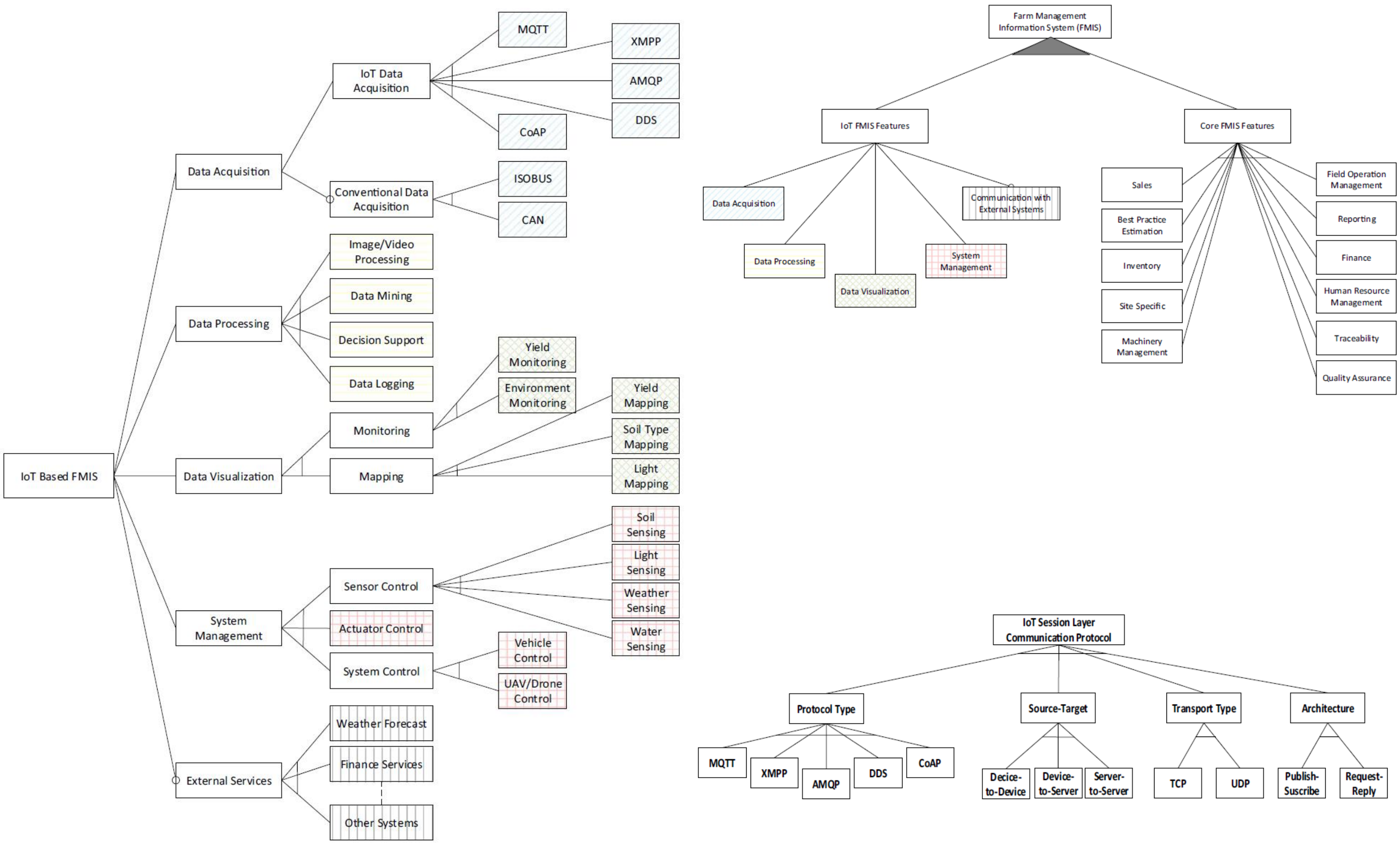
- **Feature**:
  - a distinctive property of a concept (domain model)
  - user visible characteristic of a system (requirements).

- **A feature diagram** consists of a set of nodes, a set of directed edges, and a set of edge decorations.

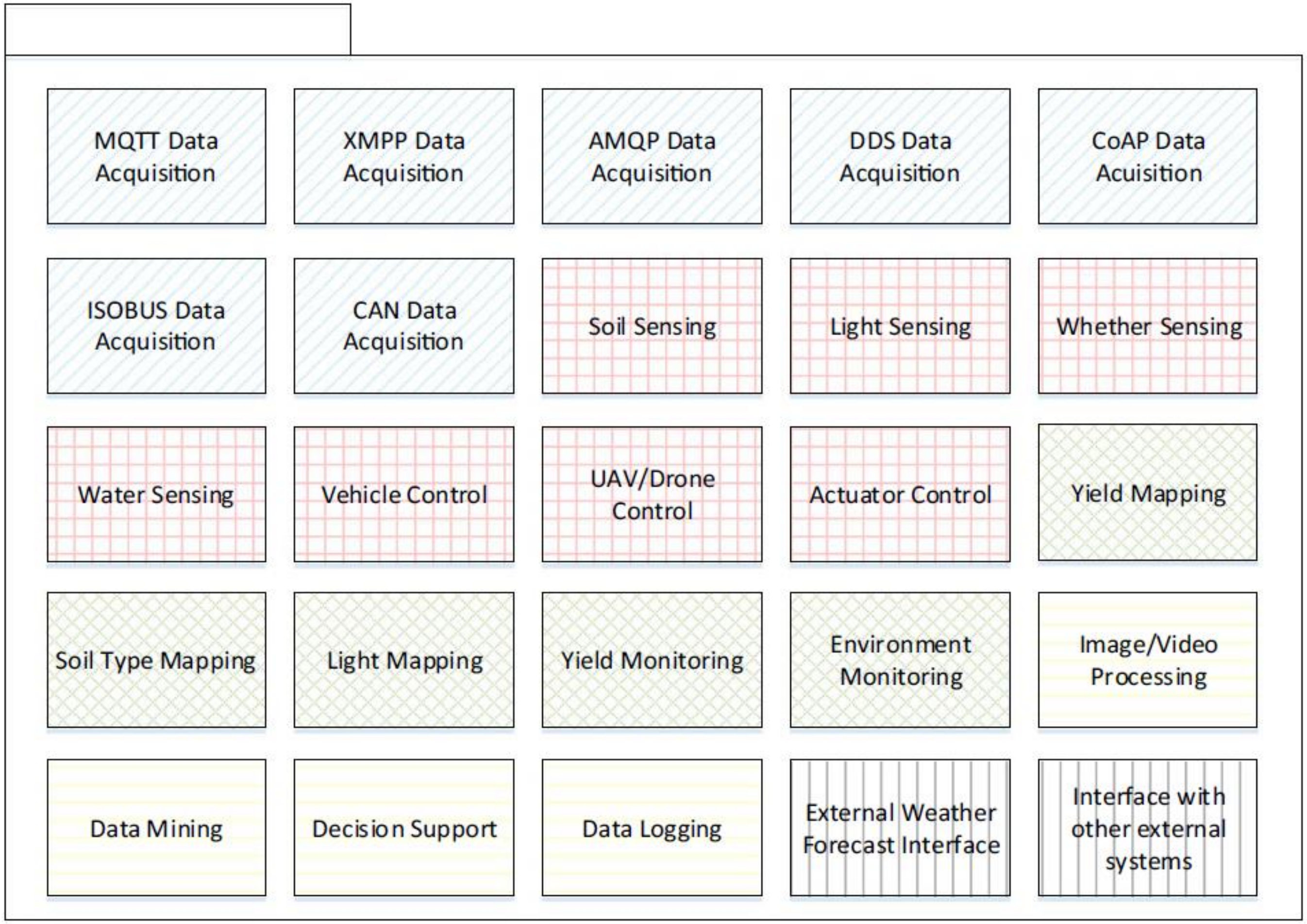


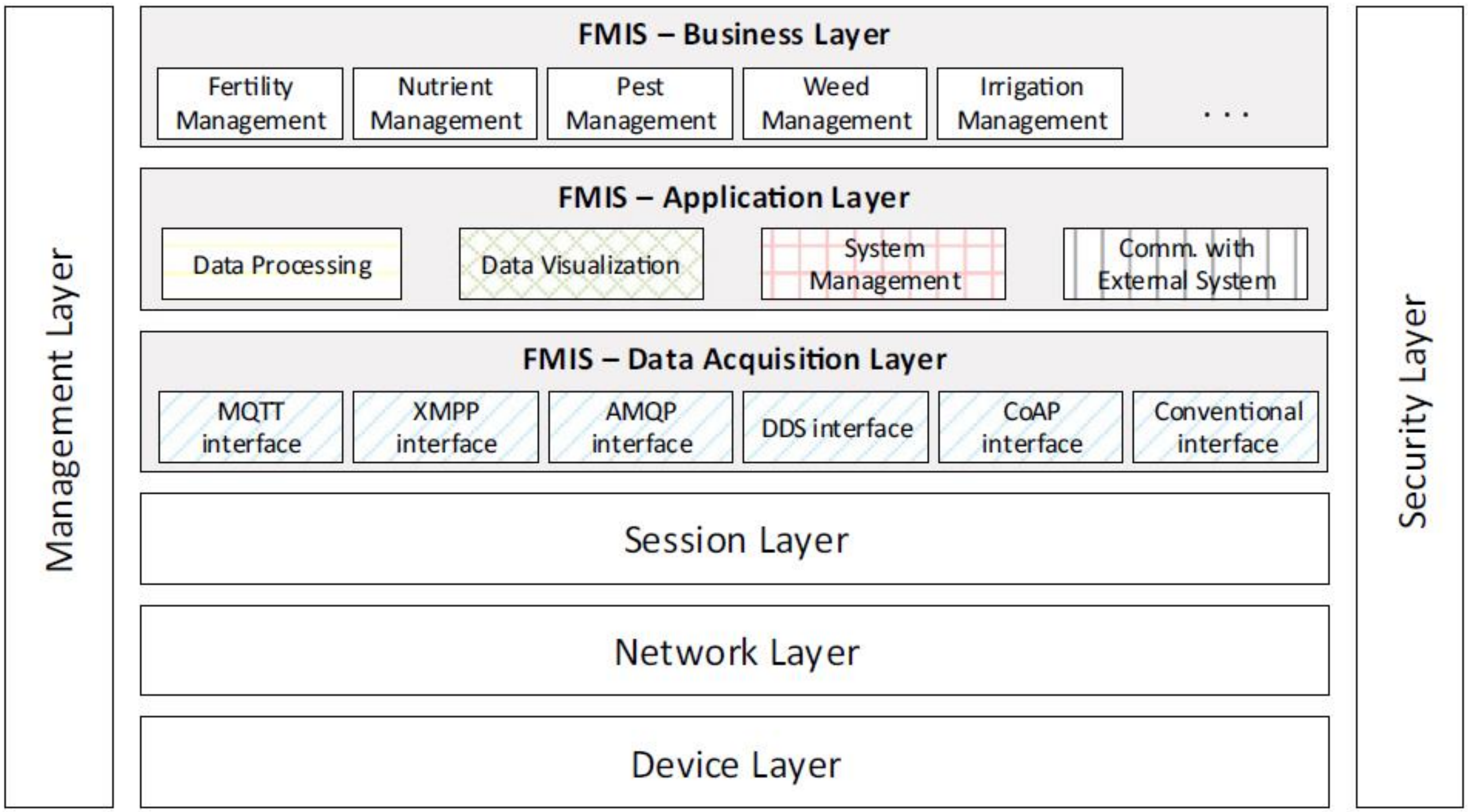
# Feature Model for IoT-Based FMIS



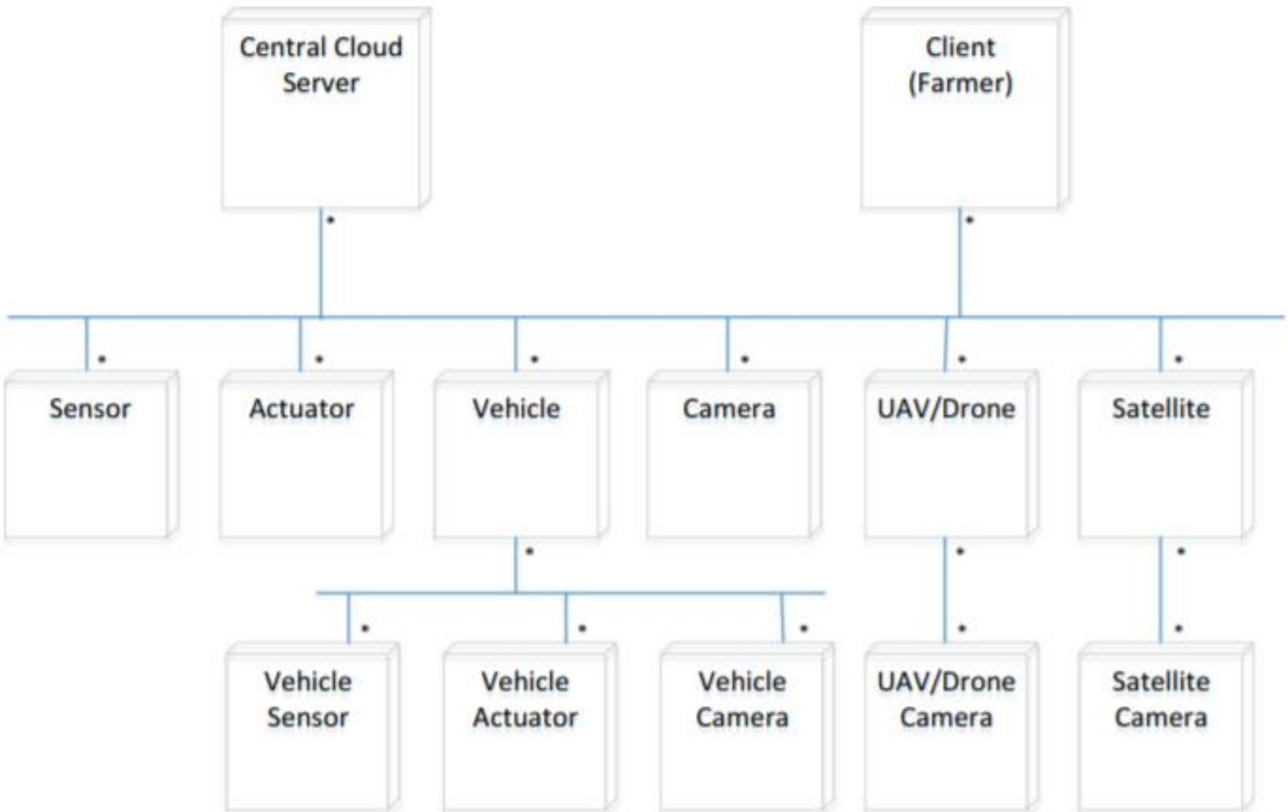
# FMIS Decomposition View



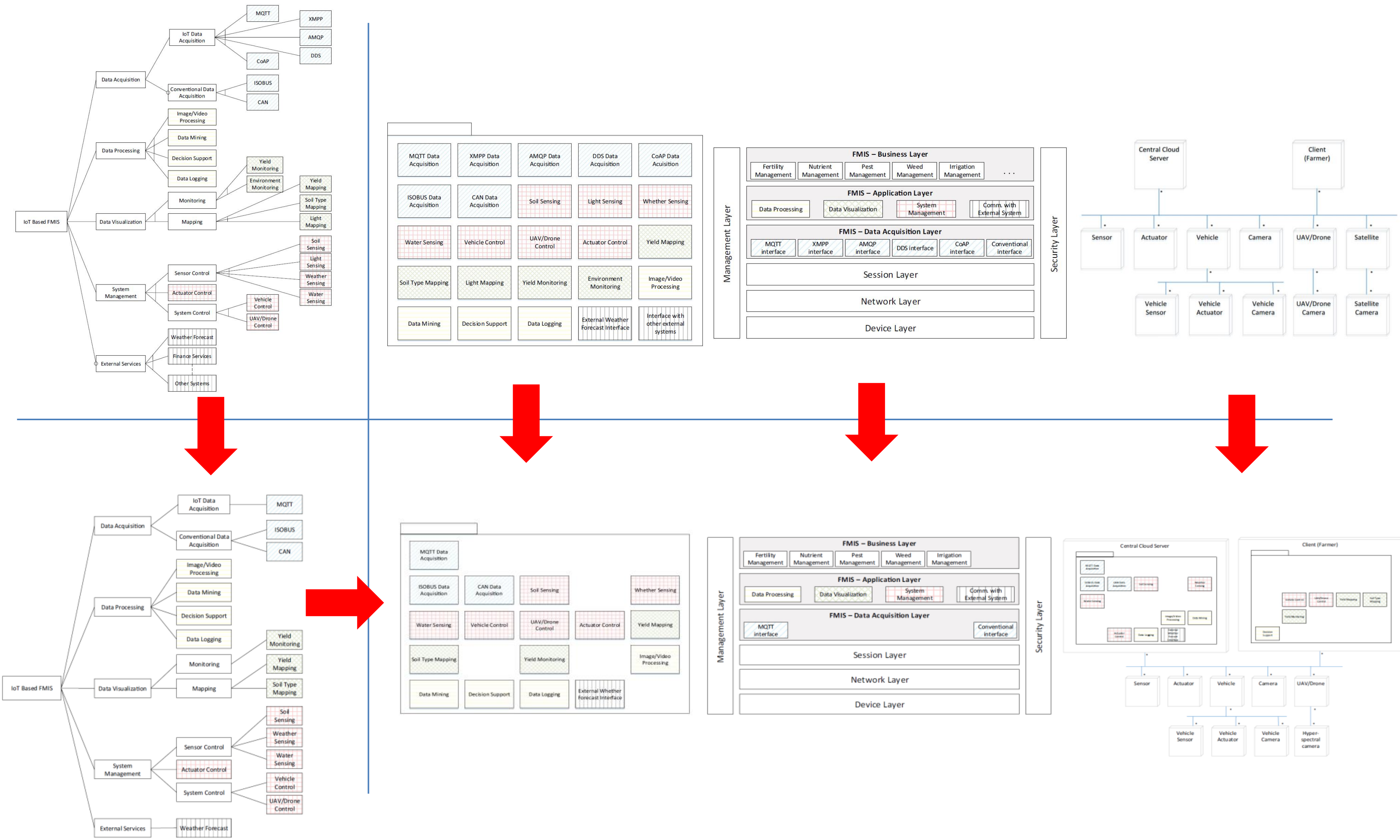
# FMIS Layered View



# FMIS Deployment View



# Case Study – Smart Wheat Production



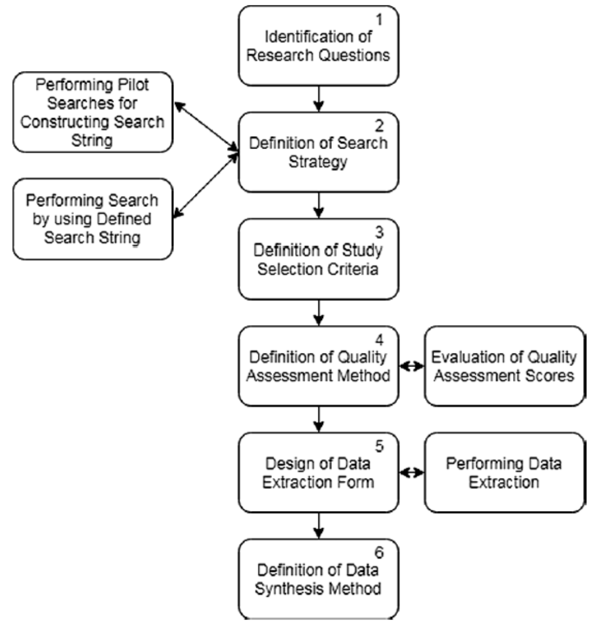
# Obstacles of FMIS

ELSEVIER
Computers and Electronics in Agriculture
Volume 157, February 2019, Pages 189-204

Review

Obstacles and features of Farm Management Information Systems: A systematic literature review

J. Tummers, A. Kassahun, B. Tekinerdogan




- RQ1: What are the current FMISs described in the literature?
  - RQ1.1: Which domains are supported?
  - RQ1.2: Which modeling approaches are applied?
  - RQ1.3: What are the delivery models?
  - RQ1.4: Who are the identified stakeholders?
- RQ2: What are the features of existing FMISs?
- RQ3: What are the obstacles to existing FMISs?

Overview of search results and study selection.

| *Source* | *After automated and manual search* | *After applying selection criteria* | *After reading complete study and quality assessment* |
|---|---|---|---|
| IEEE Xplore | 111 | 20 | 7 |
| ACM Digital Library | 102 | 10 | 5 |
| Wiley Interscience | 120 | 1 | 0 |
| Science Direct | 138 | 7 | 6 |
| Springer | 135 | 6 | 1 |
| ISI Web of Knowledge | 422 | 14 | 7 |
| Manual search | 20 | 20 | 12 |
| Total | 1048 | 78 | 38 |

# Obstacles of Farm Management IS/Ecosystem

- **Standardized data formats:** Causes problems with the interoperability between different systems and components.
- **System integration**: FMISs and their components do not integrate with each other easily. Results to problems with interchangeability between applications and platforms.
- **Adoption rate of FMIS**: The adoption of new technologies in agriculture is rarely instantaneous and multiple factors influence the decision-making processes and can therefore be a result of multiple obstacles.
- **Cost of FMIS**: Farmers find FMISs too expensive, or they are not able to see the profitability potential of an FMIS.
- **Incomplete FMIS**: Multiple FMISs are specialized for one specific task on the farm. However, these systems are therefore missing features that will cause the farmer to use multiple FMISs, instead of one FMIS that can provide in all needs.
- **Understandability**: Current FMISs are not always easy to understand and use for farmers, due to difficult user interfaces or other factors that make them complex.
- **Data size**: The accumulation of data over the years is seen as a concern
- **Connection to internet**: Some FMISs are only accessible with an active internet connection; this connection is however not always reliable in more rural areas.
- **Insufficient farmer skills**: Farmers frequently have a low level of education, and therefore farmers are not always able to obtain the full potential of FMISs.
- **Language and regional**: Sometimes FMISs are only available in one language. Furthermore, there are big regional differences between countries concerning agricultural practices; FMISs can therefore not always foresee in all farmers needs due to these differences.
- **Security**: There are currently concerns about the security and privacy of the data that is used in the FMIS.

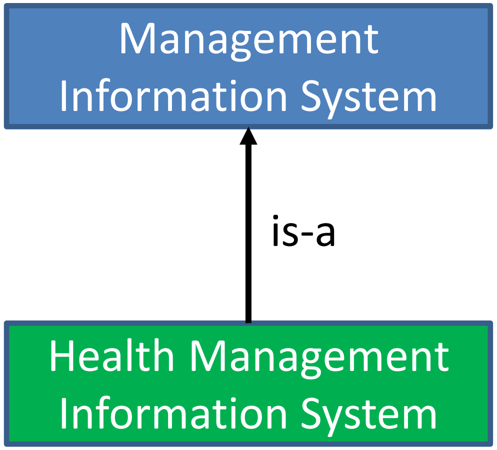
# Health Management Information Ecosystem

WAGENINGEN UNIVERSITY & RESEARCH

Radboudumc university medical center

# Health Management Ecosystem

- **health management information systems (FMIS)** is an MIS that supports the automation of data acquisition and processing, monitoring, planning, decision making, documenting, and **managing the health operations**.



# Health Management Information Systems

Computers in Biology and Medicine 137 (2021) 104785

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/compbiomed

ELSEVIER

## Obstacles and features of health information systems: A systematic literature review

J. Tummers [a], B. Tekinerdogan [a,*], H. Tobi [b], C. Catal [c], B. Schalk [d]

[a] Information Technology Group, Wageningen University & Research, Hollandseweg 1, 6706, KN, Wageningen, the Netherlands
[b] Biometris, Wageningen University & Research, Droevendaalsesteeg 1, 6708, PB, Wageningen, the Netherlands
[c] Department of Computer Science and Engineering, Qatar University, 2713, Doha, Qatar
[d] Department of Primary and Community Care, Radboud University Medical Center, P.O. Box 9101, Route 68, 6500, HB, Nijmegen, the Netherlands

ARTICLE INFO

*Keywords:*
Health information system
Systematic literature review
Features of HIS
Obstacles to HIS
State-of-the-art
Electronic health record

ABSTRACT

*Background:* Currently many healthcare systems are supported by an increasing set of Health Information Systems (HISs), which assist the activities for multiple stakeholders. The literature on HISs is, however, fragmented and a solid overview of the current state of HISs is missing. This impedes the understanding and characterization of the required HISs for the healthcare domain.
*Methods:* In this article, we present the results of a Systematic Literature Review (SLR) that identifies the HISs, their domains, stakeholders, features, and obstacles.
*Results:* In the SLR, we identified 1340 papers from which we selected 136 studies, on which we performed a full-text analysis. After the synthesis of the data, we were able to report on 33 different domains, 41 stakeholders, 73 features, and 69 obstacles. We discussed how these domains, features, and obstacles interact with each other and presented suggestions to overcome the identified obstacles. We recognized five groups of obstacles: technical problems, operational functionality, maintenance & support, usage problems, and quality problems. Obstacles from all groups require to be solved to pave the way for further research and application of HISs.
*Conclusion:* This study shows that there is a plentitude of HISs with unique features and that there is no consensus on the requirements and types of HISs in the literature.

Tummers *et al. BMC Med Inform Decis Mak* (2021) 21:210
https://doi.org/10.1186/s12911-021-01570-2

BMC Medical Informatics and Decision Making

RESEARCH **Open Access**

## Designing a reference architecture for health information systems

Joep Tummers[1*], Hilde Tobi[2], Cagatay Catal[3] and Bedir Tekinerdogan[1]

**Abstract**

**Background:** Healthcare relies on health information systems (HISs) to support the care and receive reimbursement for the care provided. Healthcare providers experience many problems with their HISs due to improper architecture design. To support the design of a proper HIS architecture, a reference architecture (RA) can be used that meets the various stakeholder concerns of HISs. Therefore, the objective of this study is to develop and analyze an RA following well-established architecture design methods.

**Methods:** Domain analysis was performed to scope and model the domain of HISs. For the architecture design, we applied the views and beyond approach and designed the RA's views based on the stakeholders and features from the domain analysis. We evaluated the RA with a case study.

**Results:** We derived the following four architecture views for HISs: The context diagram, decomposition view, layered view, and deployment view. Each view shows the architecture of the HIS from a different angle, suitable for various stakeholders. Based on a Japanese hospital information system study, we applied the RA and derived the application architecture.

**Conclusion:** We demonstrated that the methods of the software architecture design community could be used in the healthcare domain effectively and showed the applicability of the RA.

**Keywords:** Electronic patient dossier, Reference architecture, Software architecture, Health information systems, Unified modeling language

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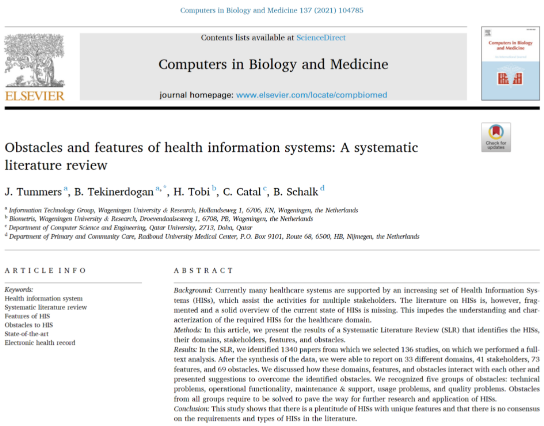
# Health Information System of Systems

# Obstacles and Features of HMIS



Computers in Biology and Medicine 137 (2021) 104785

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journal homepage: www.elsevier.com/locate/compbiomed

Obstacles and features of health information systems: A systematic literature review

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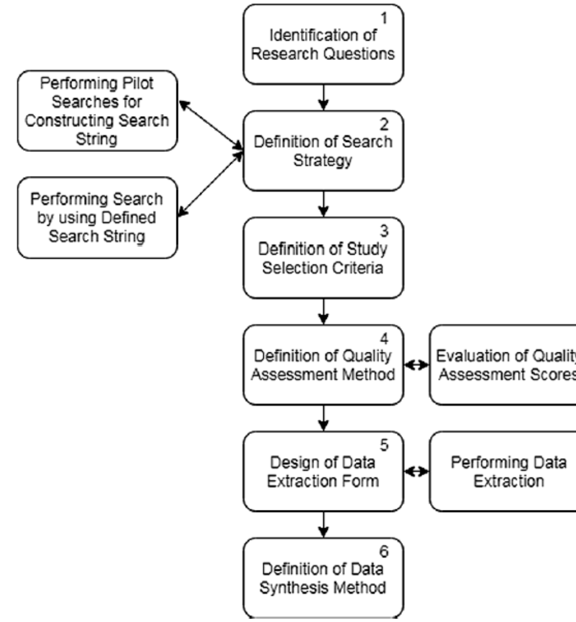
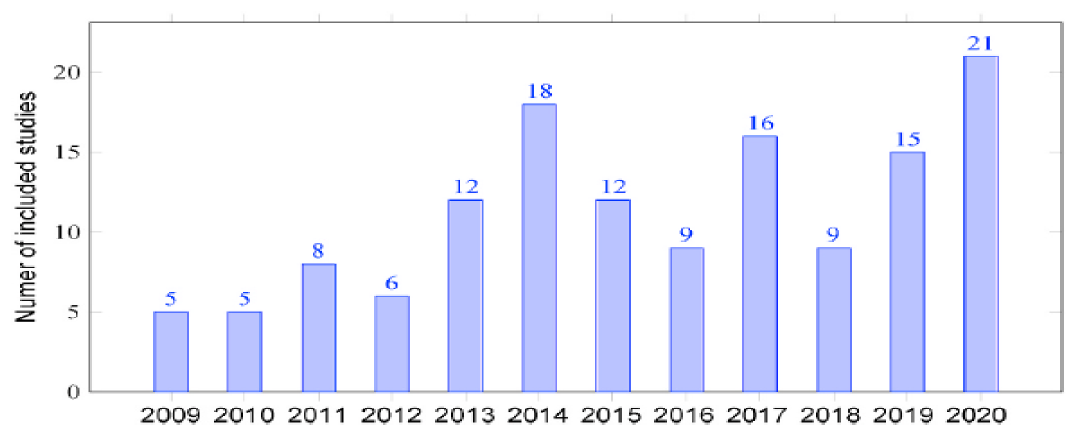




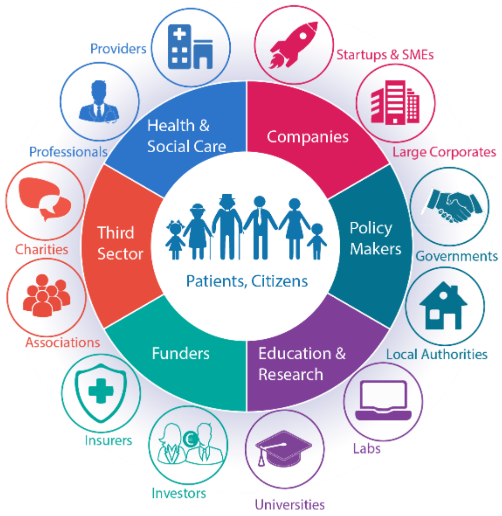
- Current HMIS
- HMIS Domains
- HMIS Stakeholders
- HMIS Features
- HMIS Obstacles



# HMIS Domains

| | | | |
|---|---|---|---|
| Hospital | 49 | Allergy and immunology | 2 |
| Primary care | 20 | Brain disorder | 2 |
| Pediatrics | 8 | Cardiology | 2 |
| Infectious disease care | 7 | Community health | 2 |
| Laboratory | 5 | Nursing | 2 |
| Medication | 5 | Surgery | 2 |
| Outpatient care | 5 | Telehealth | 2 |
| Radiology | 5 | Alternative medicine | 1 |
| Diabetes care | 4 | Care for homeless | 1 |
| Care for chronically ill | 3 | Emergency care | 1 |
| Dentistry | 3 | Geriatric care | 1 |
| Maternal-fetal medicine | 3 | Ophthalmology | 1 |
| Mental health | 3 | Public health unit | 1 |
| Neurology | 3 | Rare diseases | 1 |
| Oncology | 3 | Telemedicine | 1 |
| Palliative care | 3 | Transmural care | 1 |
| Pulmonology | 3 | | |


# HMIS Stakeholders

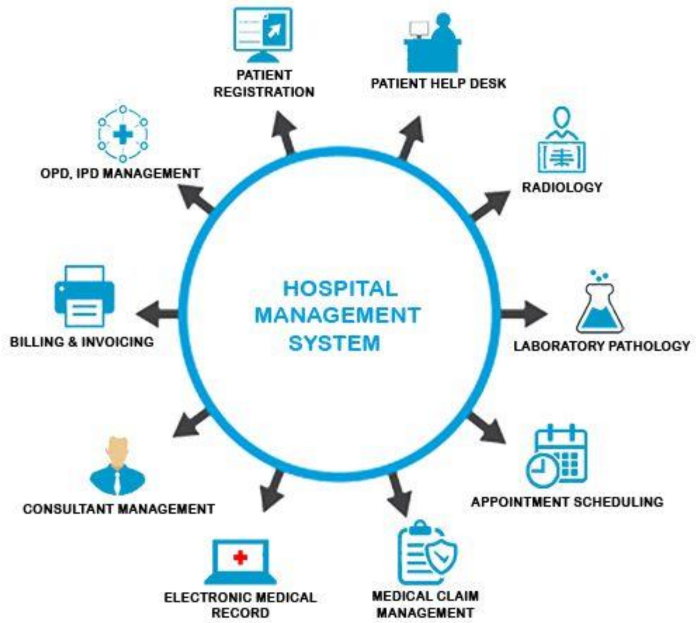



**Direct system users**

| | |
|---|---|
| Physician | 84 |
| Nurse | 63 |
| Medical specialist | 43 |
| Administrative Staff | 29 |
| Pharmacist | 19 |
| Laboratory technician | 16 |
| Therapist | 14 |
| Medical assistant | 13 |
| Regulator/policy maker | 9 |
| Resident physician | 7 |
| Secretary | 7 |
| Educator | 6 |
| Healthcare consultant | 6 |
| Data clerk | 5 |
| Dentist | 5 |
| Receptionist | 4 |
| Social worker | 3 |
| Biomedical engineer | 2 |
| Hospice staff | 2 |
| Alternative medicine practitioner | 1 |

| Group | Stakeholder | Count |
|---|---|---|
| In-direct system users | Patient | 44 |
| | Healthcare manager | 30 |
| | Researcher | 13 |
| | Patients family/relatives/representatives | 5 |
| | Student | 5 |
| | Counselor | 2 |
| | System administrator | 2 |
| | Healthcare association | 1 |
| | Insurance company | 1 |
| | National expert | 1 |
| | Health promotion worker | 1 |
| Technical stakeholder | IT-staff | 22 |
| | Healthcare informatician | 18 |
| | System developer | 12 |
| | Software vendor | 7 |
| | Statistician | 4 |
| | Technical staff | 3 |
| | IT expert | 3 |
| | System manager | 1 |
| | Technical writer | 1 |
| | External system | 1 |

# HMIS Features




| Sector specific | | General features | |
|---|---|---|---|
| Medication recording | 68 | Reporting | 57 |
| Patient record | 62 | Order management | 47 |
| Lab test results | 54 | Reminders and alerts | 45 |
| Clinical decision support and guidelines | 47 | Administration and finance | 43 |
| Diagnosis/clinical assessment | 47 | Video and image analysis | 40 |
| Patient tracking and monitoring | 41 | Documentation | 39 |
| Clinical notes | 37 | Appointments and scheduling | 33 |
| Treatment planning | 33 | Recording demographics | 28 |
| Recording vital signs | 32 | Problem list | 27 |
| Laboratory functionality | 31 | Internal communication | 27 |
| Specialist care feature | 28 | Data visualization | 20 |
| Medication prescription | 26 | Data import and export | 20 |
| Disease monitoring | 25 | Data and record exchange | 20 |
| Patient admission and registration | 24 | Staff and patient education | 17 |
| Radiology management | 24 | Data storage | 17 |
| Patient health status registration | 22 | External communication | 15 |
| Allergy recording | 19 | Data and system integration | 14 |
| Patient care overview and summaries | 19 | Security and risk management | 12 |
| Immunization and vaccination registration | 16 | Inventory management | 11 |
| Making discharge summaries | 15 | Data search | 10 |
| Consultation documentation | 14 | Workflow support | 9 |
| Referrals | 14 | Quality control | 9 |
| Patient portal | 14 | Authentication | 7 |
| Pharmacy functionality | 12 | Task management | 6 |
| Recording blood values | 10 | Remote access | 6 |
| Medical forms and questionnaires | 9 | Human resource mgmt. | 6 |
| Medical data analysis | 8 | Evaluation and benchmarking | 5 |
| Recording symptoms | 8 | Sensor management | 3 |
| Care coordination | 5 | Voice control | 2 |
| Clinical measurements | 5 | Setting goals | 2 |
| Food management | 5 | Prognosis | 2 |
| Death registrations | 4 | Help function | 2 |
| Telehealth | 4 | To do list | 1 |
| Visit management | 3 | Data sharing | 1 |
| Family planning | 1 | | |
| Informing patient and family | 1 | | |
| Lifestyle suggestions | 1 | | |
| Pain recording | 1 | | |

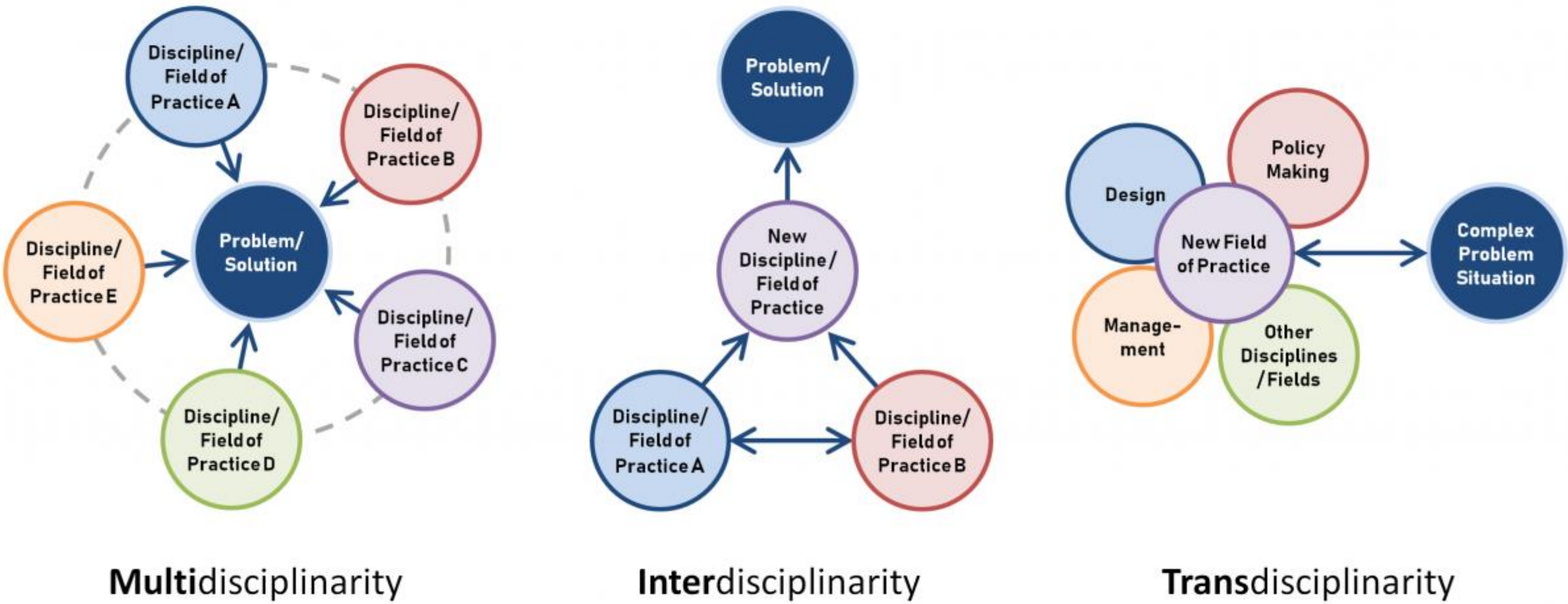
# Obstacles of HMIS

| | | |
|---|---|---|
| Technical problems | Poor interface design | 27 |
| | Lack of standards | 24 |
| | Poor security | 19 |
| | Lack of data and system integration | 18 |
| | Hardware/Power problems | 16 |
| | Poor privacy | 14 |
| | Poor data and system availability | 13 |
| | Performance problems | 11 |
| | System limitations | 10 |
| | Network problems | 10 |
| | Poor hardware availability | 10 |
| | Poor data exchange | 7 |
| | Poor system accessibility | 7 |
| | Lacking infrastructure | 6 |
| | Data and system reliability | 6 |
| | System down | 6 |
| | System installation problems | 2 |
| | Poor scalability | 2 |
| | Problems with data and system storage | 1 |
| Operational func. | Missing features | 47 |
| | Bad fit with clinical workflow | 17 |
| | Problems with specific features | 14 |
| | Captures attention away from patients | 12 |
| | Requirement of multiple systems | 6 |
| | Need to work in unique and specific setting | 5 |
| | Poor working environment | 4 |
| Maintenance & Support | Lacking professional support | 25 |
| | High system costs | 23 |
| | Poor communication | 11 |
| | Legal and bureaucratic problems | 9 |
| | Lack of help and documentation | 7 |
| | Poor system updates | 5 |
| | Low trust in supplier | 3 |

18

| | | |
|---|---|---|
| Usage problems | Limited use | 36 |
| | Time consuming to use | 21 |
| | Lacking user training | 21 |
| | Poor system usability | 21 |
| | High system complexity | 20 |
| | Uneducated users | 15 |
| | Data and system inefficiency | 13 |
| | Duplicate documentation | 10 |
| | Manual work | 7 |
| | Incorrect usage | 6 |
| | Navigation issues | 6 |
| | Low trust in system | 6 |
| | Low user satisfaction | 5 |
| | User disagreement with system | 4 |
| | Finding data | 4 |
| | Problems related to meeting user needs | 4 |
| | Information overload | 2 |
| | Lack of awareness | 2 |
| | Maximum use of system to usage | 2 |
| | Low system usefulness | 2 |
| | Hygiene problems | 1 |
| | Use of free text for registrations | 1 |
| Quality problems | Lack of data and system interoperability | 24 |
| | Low data quality | 21 |
| | Poor system development | 12 |
| | Data and system inconsistencies | 11 |
| | Data loss | 10 |
| | Faulty system | 9 |
| | Data input/output/Propagation problems | 8 |
| | Poor data integrity | 4 |
| | Low system accuracy | 4 |
| | Poor patient safety | 2 |
| | Fragmented data | 2 |
| | Medical error | 2 |
| | Poor system natural language | 2 |
| | Data interpretability | 1 |

# Interdisciplinary and Transdisciplinary Approach



# Design Challenges – Digital Ecosystems

- Which domains are needed for digital ecosystems
- What are the stakeholders for each domain?
- What are the concerns?
- What are the required design viewpoints for digital ecosystems?
- Modeling approaches for digital ecosystems?
- Design Methods for digital ecosystem?
- Design Patterns/Tactics/Perspectives for digital ecosystems?
- Evaluation Method for digital ecosystems?
- Trade-off Analysis for digital ecosystems?
- Governance of digital ecosystems?
- Alignment of governance with systems/technology?
- Simulation of digital ecosystems?
- ….

# Conclusion

- A **system** is a set of interacting or interdependent components forming an integrated whole
- Increased level of scale and the interconnection of systems has led to the notion of **system of systems**
- Digitalization of systems has led to **cyber-physical systems** (of systems)
- An **ecosystem** is a system or system of systems with symbiotic relations of independent players that together constitute target a coherent solution
- a **business ecosystem** is a dynamic group of largely independent economic players that create products or services that together constitute a coherent solution
- Business ecosystems are increasingly currently **IT-controlled** leading to digital business ecosystems

# Conclusion

- **Many unsolved challenges** can be identified for designing, operating, and maintaining (digital) business ecosystems

- **Design** of digital business ecosystems is one of the key artifacts that has a systemic impact on the overall ecosystem

- **Existing system and system of systems engineering paradigms need to be enhanced** to cope with the **challenges** of digital business ecosystems

- Designing and analyzing digital business ecosystems requires an **interdisciplinary and transdisciplinary approach**