Towards an Integration of Fusion of Information and Analytics Technologies (FIAT) to Improve Dependability and Security in Complex Systems

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Outline

• Cyber-physical and social systems (CPSS)
• CPS (Cyber-Physical Systems) versus IoT (Internet of Things)
• Dependability in systems
• FIAT (Fusion of Information and Analytics Technologies)
• Integration of FIAT
• Design of FIAT-based support systems
Outline

• Cyber-physical and social systems (CPSS)
Objective: to improve and ensure ‘dependability’ in such complex environments
Internet of Things (IoT)
Network of Networks
... Web 3.0, Web 4.0 ...
System of Systems
Cyber-Physical Systems (CPS)
Outline

- **CPS** (Cyber-Physical Systems) *versus* **IoT** (Internet of Things)
Cyber-physical systems

... and related terms: Internet of Things

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<th>OR</th>
<th>Internet of things</th>
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“The frontier between CPS and Internet-of-Things has not been clearly identified since both concepts have been driven in parallel from two independent communities, although they have always been closely related.” [Koubâa, 2009]

A quick glance into the web:

“Cyber Physical System is the US version of the ‘internet of things’”

“Internet of Things & Services, M2M or cyber physical systems are much more than just buzzwords for the outlook of connecting 50 billions devices by 2015.”

“The term ‘Internet of Things’, originally aiming at RFID technologies, is smoothly becoming synonymous for cyber-physical systems.”

Vision: Internet of Things, Data and Services e.g. Smart City

Vision: Cyber physical systems e.g. intelligent networked road junction
Cyber-Physical Systems (CPS) versus Internet of Things (IoT)

- Pervasive networks
- Ambient intelligence
- Ubiquitous computing
Cyber-physical systems

... and related terms: Internet of Things & Industry 4.0

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**Shared**

- Vision
  - Large-scale distributed computing systems of systems
  - Computation and "intelligence" is not decoupled from environment

- Core Technology
  - Internet as large-scale network
  - Embedded systems (= intelligent components)

**Distinct**

- Scientific Community
  - Internet of Things driven from computer sciences, Internet technologies driven by EC
  - Cyber-physical system driven from engineering aspects driven by the NSF

- Philosophy, focus
  - Internet of Things focusing on openness and on the network - virtuality
  - Cyber-physical system focusing on the physical system behind, often a closed-loop system

**For all practical purposes:**

- Today: more or less synonym
- Industry 4.0 as a special field of application
Outline

• Dependability in systems
CPSS ----- System far-reaching Goals

- Safety-critical systems
  (Failure results in loss of life, injury or damage to the environment - e.g. nuclear power plants)

- Mission-critical systems
  (Failure results in failure of some goal-directed activity - e.g. military systems)

- Business-critical systems
  (Failure results in high economic losses - e.g. bank accounting system)

Cyber-Physical and Social Systems (CPSS)
(Merging computing, networking and society with physical systems)

Far-reaching Goals
- 24 hours /7 days availability,
- 100% reliability,
- 100% connectivity, predictability and repeatability,
- Real time,
- Store anything and everything forever,
- + social requirements such as: young to old, rich and poor, able and disabled, ...
- ...

CPSS-Transport
CPSS-Energy
Dependability in systems

- Availability: The ability of the system to deliver services when requested.
- Reliability: The ability of the system to deliver services as specified.
- Safety: The ability of the system to operate without catastrophic failure.
- Security: The ability of the system to protect itself against accidental or deliberate intrusion.
Outline

- **FIAT** (Fusion of Information and Analytics Technologies)
FIAT?

- Fusion of Information and Analytics Technologies
- If properly assembled (integration), FIAT can provide solutions to dependability in systems
Analytics -1

- What are we doing?
  - Now
    - Operational System
- What have we done?
  - Historically
    - Data Warehouse System
- What should we be doing?
  - Future
    - Analytics System

Business value perspective

Technical implementation perspective

Descriptive
  (clustering, association, …)

Predictive
  (classification, regression, …)

Prescriptive
  (optimization, …)
Analytics - 2

Descriptive Analytics:
- gain insight from historical data with reporting, scorecards, clustering etc.

Predictive Analytics:
- analyze current and historical facts to make predictions about future, or otherwise unknown, events.

Prescriptive Analytics:
- recommend decisions using optimization, simulation etc. etc.

List of techniques for “analytics”

- test hypothesis, regression analyses,
- probability theory, sampling, inferencing,
- logic-based expert systems, fuzzy logic,
- multi-agent systems, bayesian networks,
- autoregression, kalman filters,
- classification, optimization techniques,
- hidden Markov models, dynamic bayesian networks, clustering,
- neural network, information foraging,
- machine learning, data mining,
- intelligent filtering, ontologies,
- MapReduce technologies,
- workflow systems, time-series analysis,
- visualisation, mixed-initiatives,
- links analysis, graph-based approaches
- ...

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Information fusion

Quantitative Approaches
- Probability Theory
- Dempster-Shafer Theory
- Fuzzy Sets Theory
- Possibility Theory
- Conditional Events Theory
- Rough Sets Theory
- Random Sets Theory

Qualitative/Symbolic Approaches
- Classical Logic: Propositional Logic
- Classical Logic: First-Order Logic
- Modal Logics and Knowledge Logics
- Nonmonotonic Logics

Hybrid and Graphical Approaches
- Probabilistic Logic
- Fuzzy Logic
- Possibilistic Logic
- Incidence Calculus
- Bayesian Networks
- Valuation-based Systems
BigData (4Vs dimensions)

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<tr>
<th>Variety</th>
<th>Data in many forms: structured and unstructured, text, multimedia</th>
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<tr>
<td>Volume</td>
<td>Data at scale: terabytes to petabytes of data</td>
</tr>
<tr>
<td>Velocity</td>
<td>Data in motion: analysis of streaming to enable decisions within fractions of second</td>
</tr>
<tr>
<td>Veracity</td>
<td>Data uncertainty: managing the reliability and predictability of inherently imprecise data types</td>
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Fusion of Information and Analytics Technologies
Outline

• Integration of FIAT
The art of steering

Cybernetics is **about having a goal** and taking action to achieve that goal.

**Cyber-Physical Interface:**

*Cybernetics Functions:* Surveillance/Monitoring-Integration-Coordination-Control

*System Dependability:* Maintainability-Security-Reliability-Availability-Safety

*Quality of Information (QoI):* Accessibility-Intrinsic-Contextual-Representational

*Networks Evolution:* Internet of Things (IoT), Web3.0, Semantic Web...etc.
GIT = Generalized Information Theory
  e.g. Information and knowledge modeling, uncertainty representation, ontologies, graphs, ... etc

MAS + GIT
  e.g. machine learning
  Multiple Classifiers
  Aggregation/Combination

GIT + Dec.
  e.g. Partial-Observable Markov Process,
  Multi-criteria decision making

MAS = Multi Agent Systems
  e.g. Multisensor Systems, Distributed systems

OR = Operational Research
  e.g. Decision theories,
  Scheduling & Planning
  Optimization, Risk Analysis

MAS + Dec.
  e.g. Game theory, complex systems theory,
  Networks theory, collective behaviour, nonlinear
  dynamics, evolution and adaptation, emergence,
  complex adaptive systems.
Design of FIAT-based systems
Three main poles

• Characterisation of information including context
• Imperfections: uncertainty and state of ignorance – quality of information
• Actions --- goals
Accessibility (characterizes information accessibility. Accessibility might be physical as well as organizational.)

Representational (addresses the formal representation of the problem and its context)

Intrinsic (characterizes an information element in terms of its nature, interpretation and modeling while considering it as "independent" entity, out of any global fusion context)

Contextual (characterizes an information element in terms of its impact, completeness, relevance, conflict, and redundancy within a global fusion context)

Interpretability
Ease of understanding
Representational consistency
Conciseness of representation
Manipulability
Accuracy
Believability
Objectivity
Reputation
Value-added
Relevancy
Timeliness
Completeness
Amount-of-data

(Wang and Strong)
(Quality of Information)
- Accuracy
- Completeness
- Consistency
- Correctness
- Currency
- Precision
- Relevance
- Timeliness
- Uncertainty
- Service Characteristics
- Sharability
- Source Characteristics

(Quality of Decisions)
- Accuracy
- Completeness
- Consistency
- Correctness
- Currency
- Precision
- Relevance
- Timeliness
- Uncertainty

(Survivability)
- Availability
- Safety
- Security
- Maintainability
- Reliability
- ...

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Conclusion

- Cyber-security has to be treated as part of the design not separated
- Along with other dimensions of system dependability
- Human - System & technologies integration

Cyber-Physical Interface:

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