Developing Meta Systems Architectures for Leading Innovation with Complex Societal and Technical Challenges

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Developing Meta Systems Architectures for Leading Innovation

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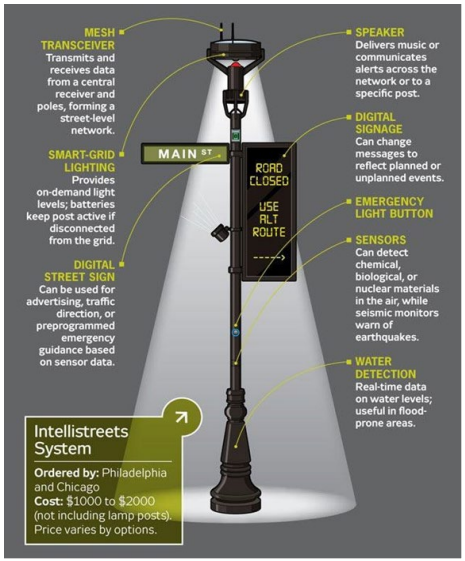

http://www.popularmechanics.com/technology/infrastructure/a7437/smart-everything-even-lamp-posts-are-now-connected/

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Changing Human Living Behaviors

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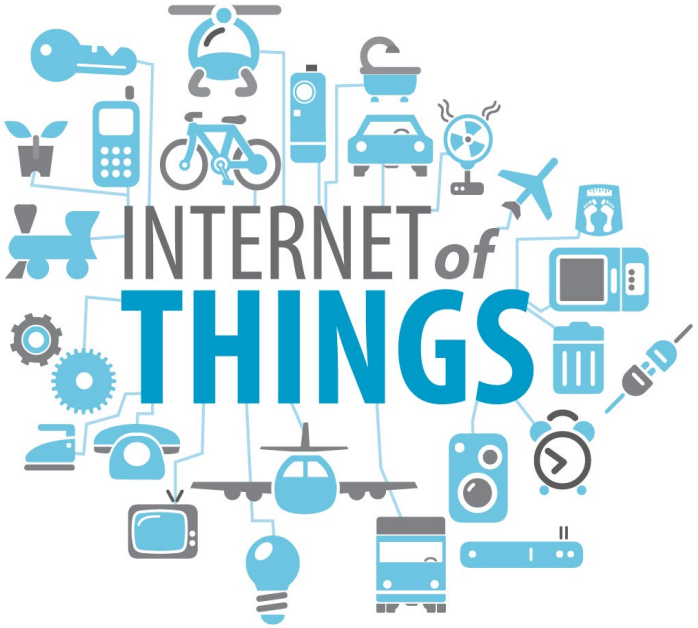

"The network of physical objects that contain embedded technology to communicate and interact with their internal states or the external environment."

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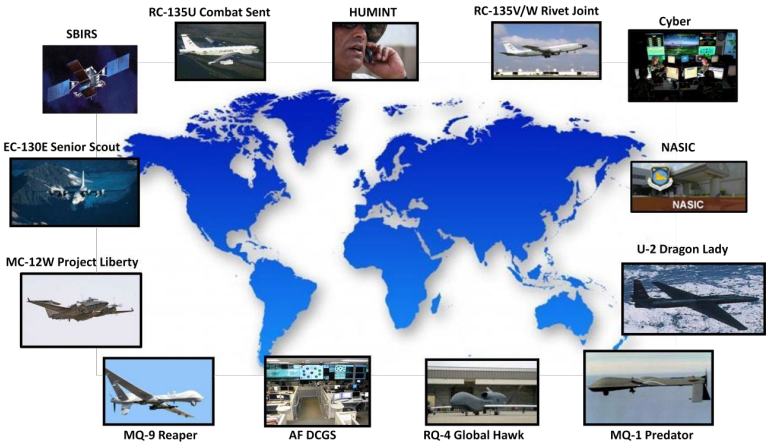
Internet of Things for Defense



Internet of Things for Manufacturing

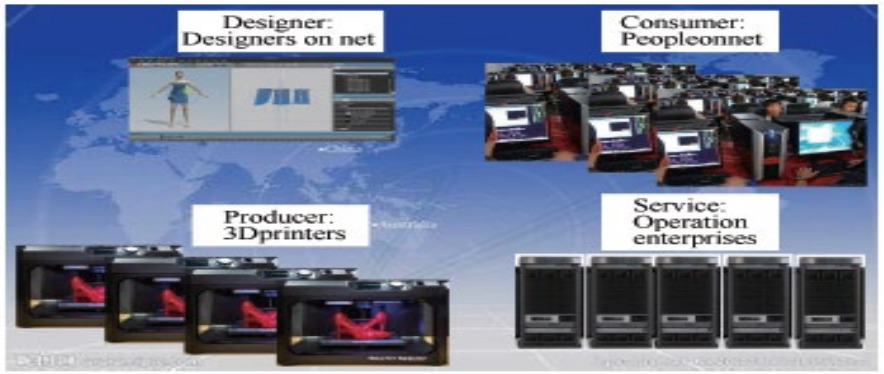


Fig. 4. Social manufacturing array with 3D printing centers.

From Mind to Products: Towards Social Manufacturing and Service Gang Xiong, et.al. IEEE/CAA JOURNAL OF AUTOMATICA SINICA, VOL. 5, NO. 1, JANUARY 2018

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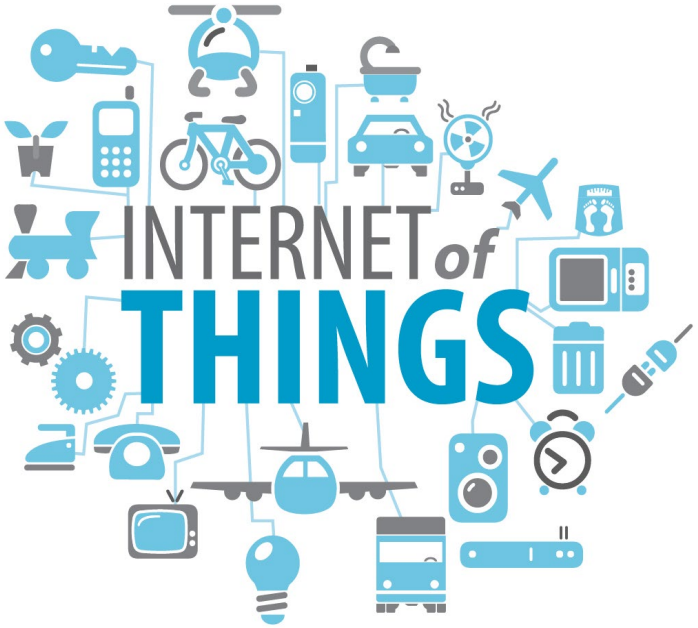

"This is a complex adaptive systems that can have emergent behavior and requires systems integration and engineering in their design and operation."

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Complex Systems

A system with a large collection of interacting elements is said to be complex if there exists emergent global dynamics resulting from the actions of its parts rather than being imposed by a central controller.

Complex Systems

A system with a large number of elements maybe complicated but not complex. The distinguishing characteristics of a complex system are:

- Large number of interacting agents
- Self-organizing collective behavior, i.e., *emergent* behavior
- Emergent behavior does not result from the existence of a central controller
- Open systems
- System boundaries are difficult to determine
- Exhibit nonlinear input-output relationships

Developing Meta Systems Architectures for Leading Innovation

Order and Chaos

- Order and structure are vital to life
- Patterns are ubiquitous both in natural and man-made systems
- Order ensures consistency and predictability
- Order makes the creation of systems possible
- However, too much order leads to rigidity
- Inflexibility suppresses creativity

- Chaos leads to disorder and unpredictable behavior
- Chaos constantly changes the rules and the environment creating instability
- However, Chaos leads to emergent behavior
- Chaos allows novelty and creativity

Chaos and order are two complementary states of our world. A dynamic balance exists between the two states. Sufficient order is necessary for a system to maintain an ongoing identity, along with enough chaos to ensure growth and development.

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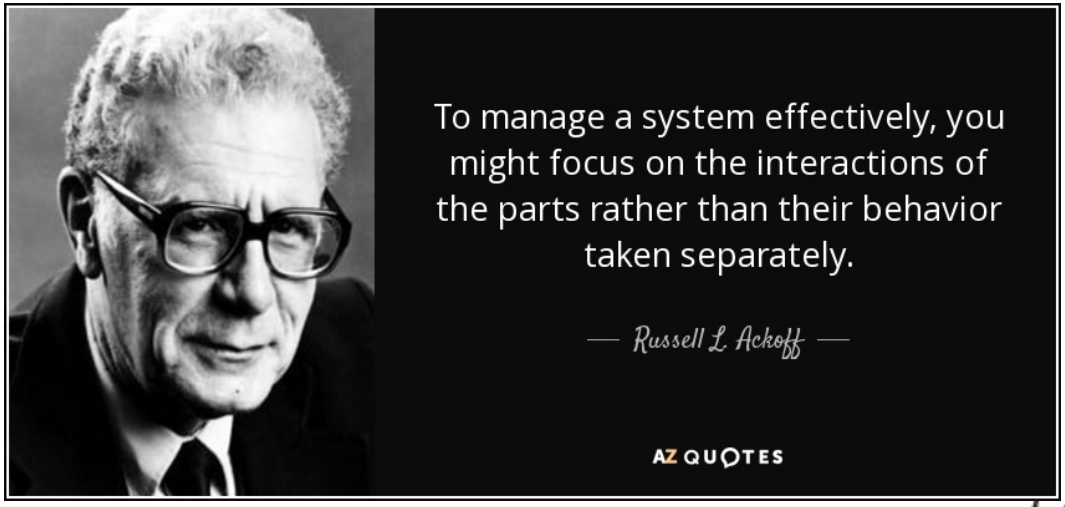

MANAGEMENT SCIENCE
Vol. 17, No. 11, July, 1971
Printed in U.S.A.

TOWARDS A SYSTEM OF SYSTEMS CONCEPTS*

RUSSELL L. ACKOFF

University of Pennsylvania

The concepts and terms commonly used to talk about systems have not themselves been organized into a system. An attempt to do so is made here. *System* and the most important types of system are defined so that differences and similarities are made explicit. Particular attention is given to that type of system of most interest to management scientists: *organizations*. The relationship between a system and its parts is considered and a proposition is put forward that all systems are either variety-increasing or variety-decreasing relative to the behavior of its parts.

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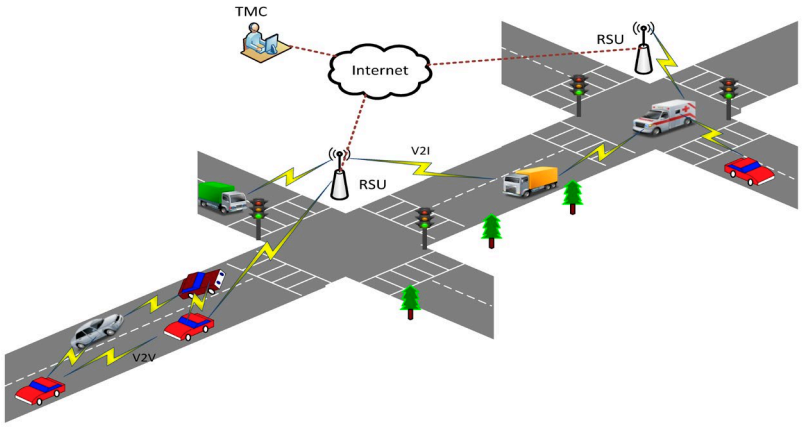
Complex Systems as Networks

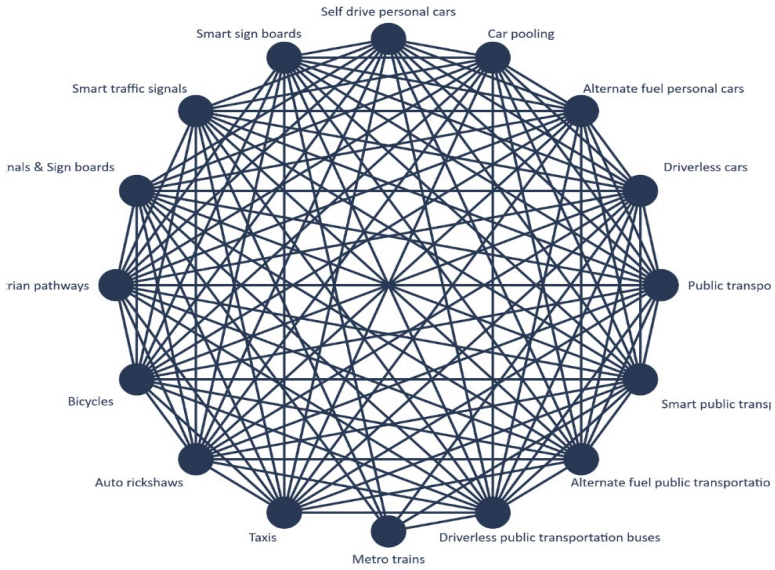
A complex system can be represented as a network where;

Elements ↔ vertices

Interactions ↔ edges

An edge between 2 vertices means they interact.





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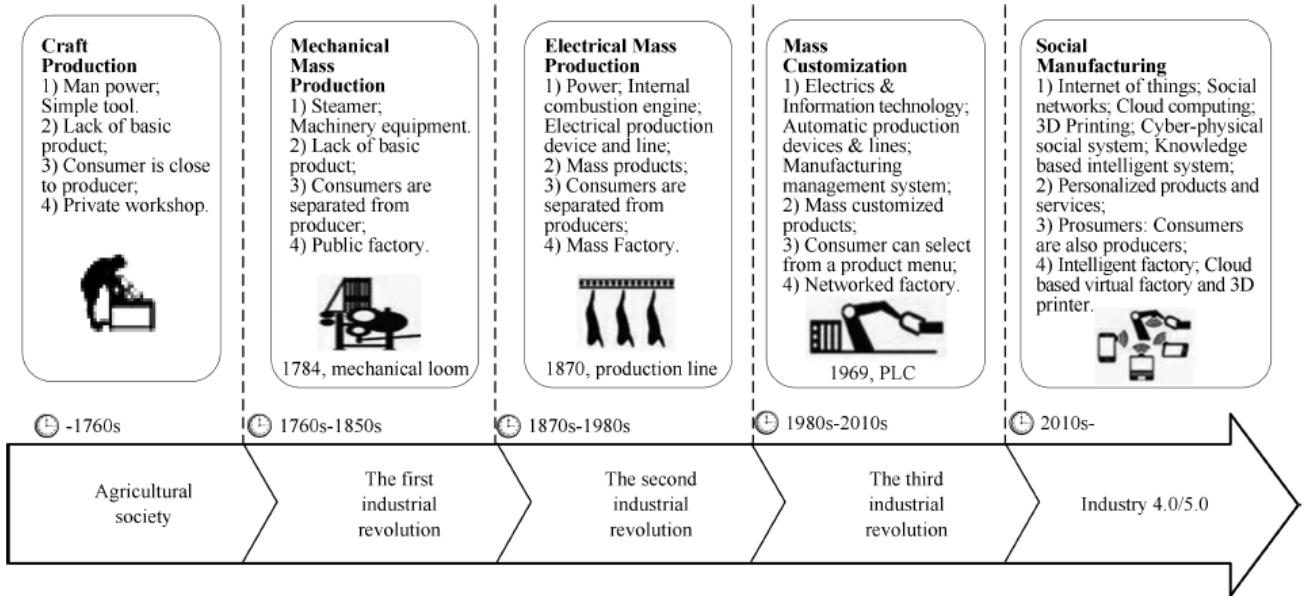
Complex Systems as Networks



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Axiomatic Basis for Emergence in Cyber Physical Systems

Holism suggests that we cannot understand a complex system through reduction to the component or entity level.

The concept of system purpose suggests that the purpose of a system is "what it does".

Pluralism is a systems concept that recognizes there may be multiple purposes/objectives in play at the individual, entity, and enterprise levels.

Axiomatic Basis for Emergence in Cyber Physical Systems

The knowledge of a complex CPS is always *incomplete* and *speculative*.

System darkness is a systems concept that recognizes there can never be complete knowledge of a system.

Boundaries in an CPS are ambiguous, fluid, and negotiable.

Axiomatic Basis for Emergence in Cyber Physical Systems

Context is the circumstances, factors, conditions, and patterns that both enable and constrain a complex system solution, deployment of that solution, and interpretation of the results of solution deployment.

For CPS, the context can dominate the solution space and may be more important than technical aspects of a solution.

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Axiomatic Basis for Emergence in Cyber Physical Systems

Dynamic stability holds that a system remains stable as long as it can continue to produce required performance during environmental turbulence and changing conditions. Maintenance of stability, or dynamic equilibrium

As the CPS environment and context change, commensurate patterns/properties emerge to make the appropriate compensations necessary for maintenance of stability.

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Axiomatic Basis for Emergence in Cyber Physical Systems

The Meta-Architecture provides the structure of relationships that integrates the CPS

- –It structures the appropriate balance to relieve tensions between
  - – The autonomy of subsystems and the integration of the CPS as a whole,
  - –Purposeful design and self-organization,
  - –Focus on maintaining stability or pursuing change .
- –Emergence will produce those patterns/properties that are necessary to resolve structural tensions and maintain CPS viability.

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Cyber Physical Systems for Next Decade

There will be *multi-faceted systems* in different levels of implementation that entail complex logic with many levels of reasoning in intricate arrangement, organized by web of connections and demonstrating self-driven adaptability which are designed for autonomy and exhibiting emergent behavior that can be visualized.

They will impact manufacturing industry, defense, healthcare, energy, transportation, emergency response, agriculture and society overall.

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Cyber Physical Systems for Next Decade

The success will depend on how the current challenges related to;

Cybersecurity,
Interoperability,
Privacy,
Human System Integration
are handled.

Industry 4.0, Society 5.0 are the term used

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Platform for Social Manufacturing and Service

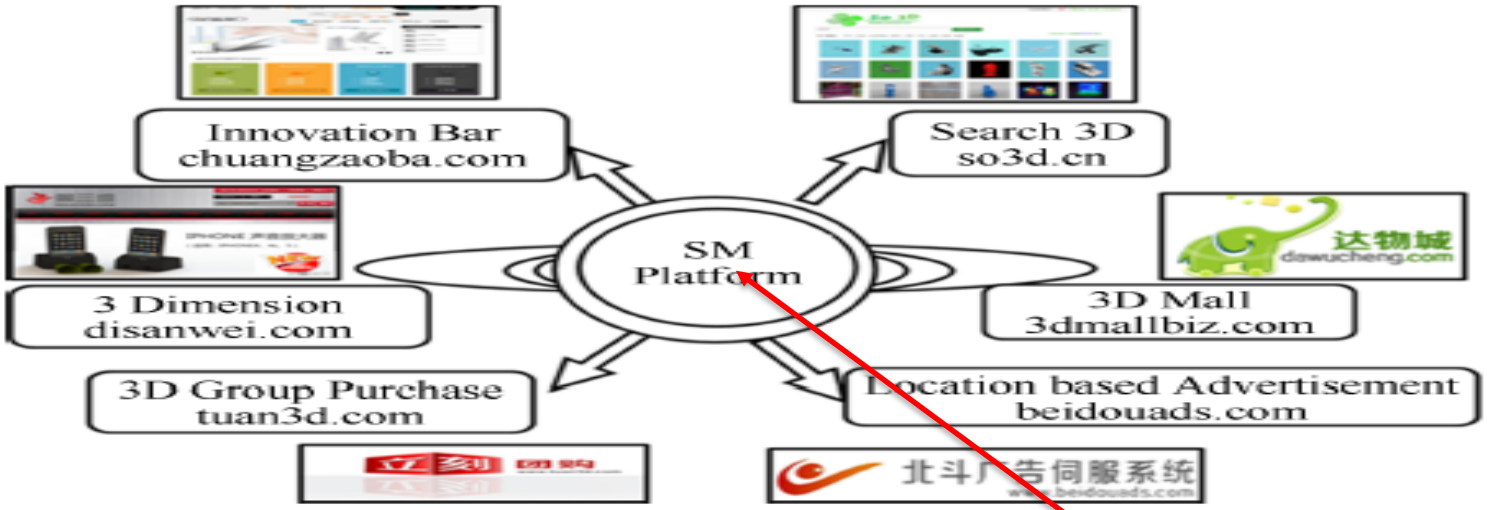

Fig. 6. Type 2 SM platform with 3D printing.

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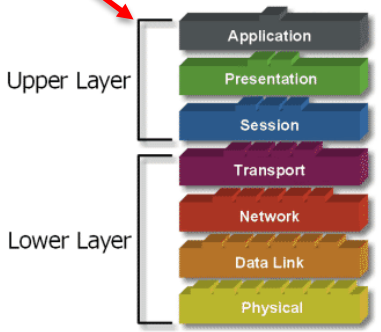

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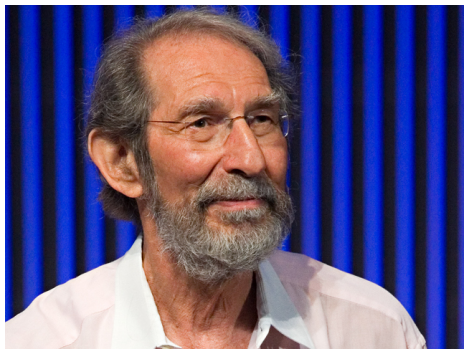
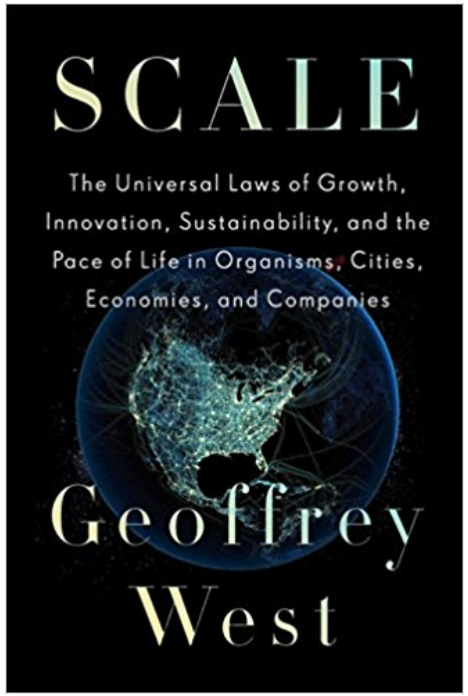
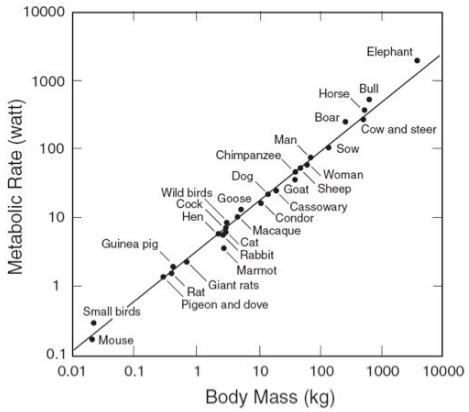
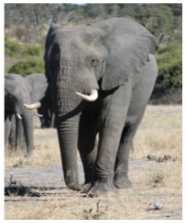
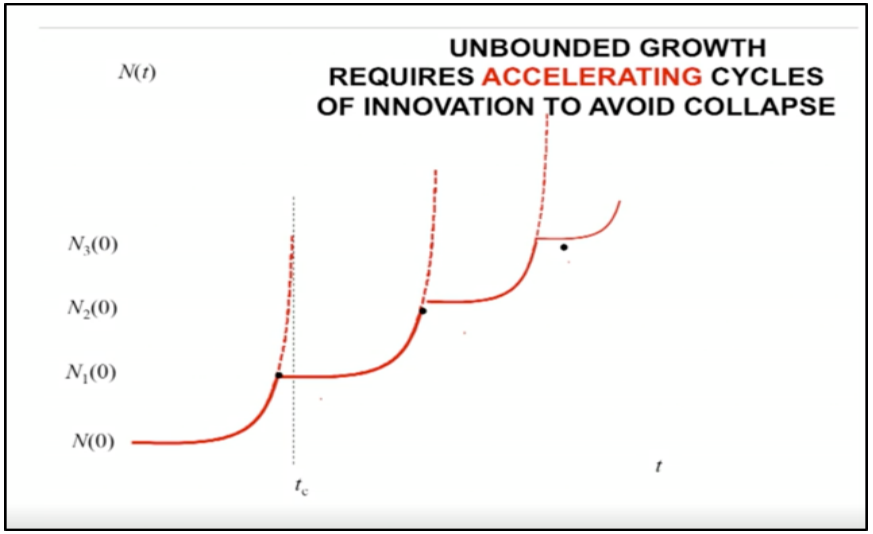








SLOPE = ¾ < 1 SUB-LINEAR ECONOMY OF SCALE



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Developing Meta Systems Architectures for Leading Innovation

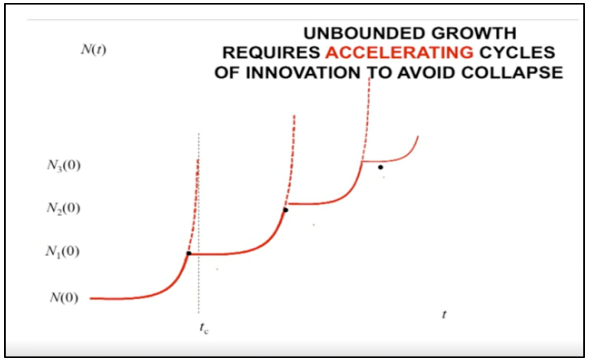
How can we maintain accelerating cycles of innovation to avoid collapse?

Developing Meta Systems Architecture

Executable Architectures for Behavior Verification

- Model Based Systems Engineering
- Model Based Engineering
- Simulation and Modeling

Development of Digital Twins



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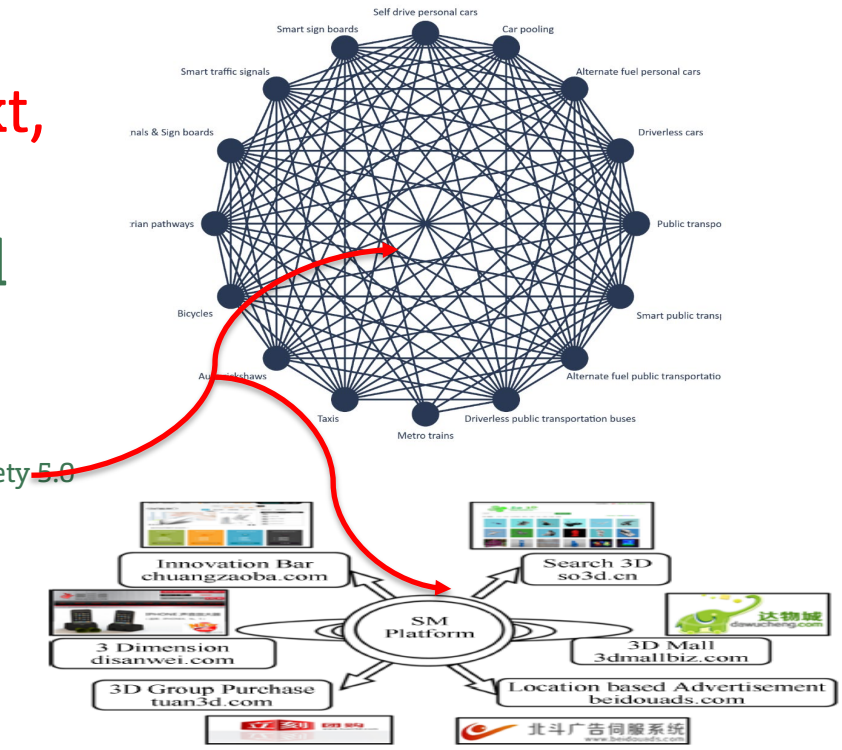
Developing Meta Systems Architectures for Leading Innovation

Developing Meta Systems Architectures

Can we determine these architecture based on context, dynamic stability and pluralism using a structured interactive approach?

Human System Integration,
Cybersecurity,
Interoperability, Privacy,
Safety,

Industry 4.0/ Society 5.0



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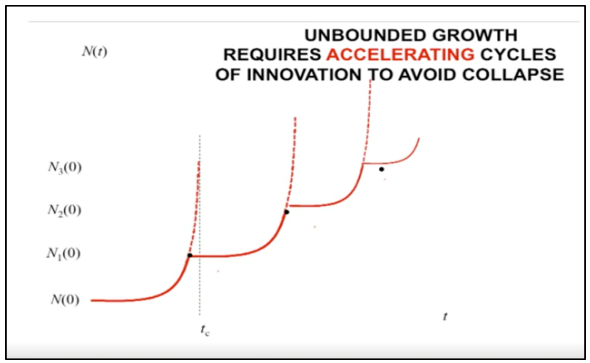
Developing Meta Systems Architectures

- Structuring the modeling effort (context)
- Optimization methods yielding targeted solution sets (pluralism)
- Visualization of architectures (context)
- Interactive architectures allowing
- "what-if" experimentation
- (dynamic stability)



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Developing Meta Systems Architectures

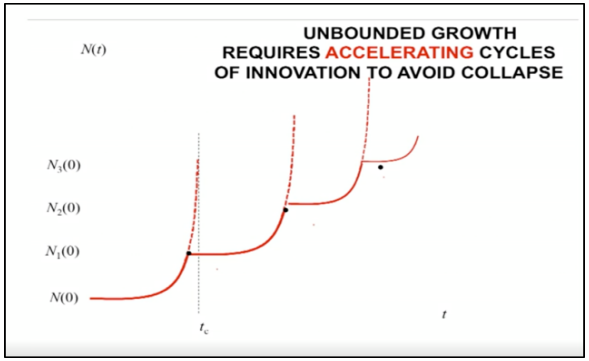
SoS Explorer is Missouri S&T's solution
http://emse.mst.edu/sos-explorer/

A novel optimization method called "MOEA-DM" tailored to the needs of cyber physical systems

Many-objective optimization

Use of clustering to cultivate a limited set of solutions of interest

Visualization of architectures
Interactive "what-if" experimentation



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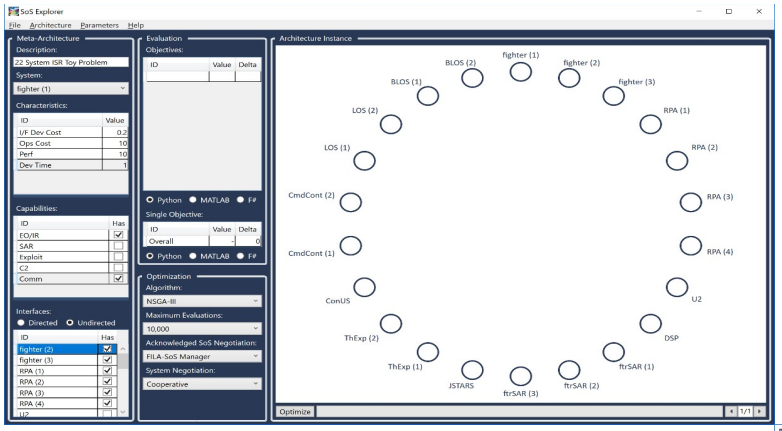
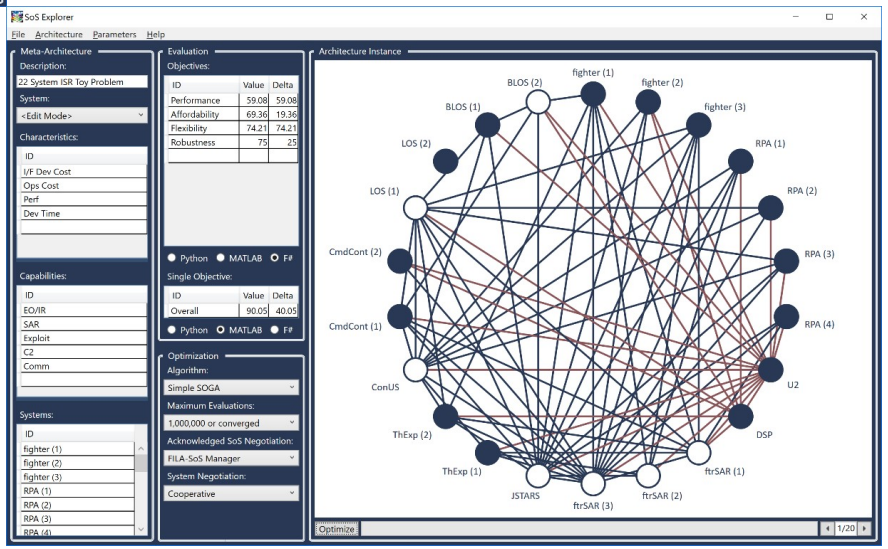
Developing Meta Systems Architectures for Leading Innovation

Developing Meta Systems Architectures





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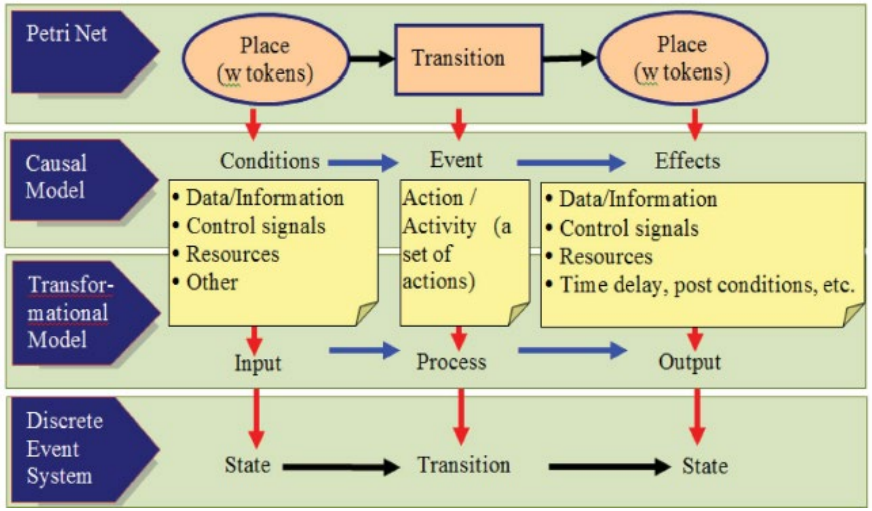
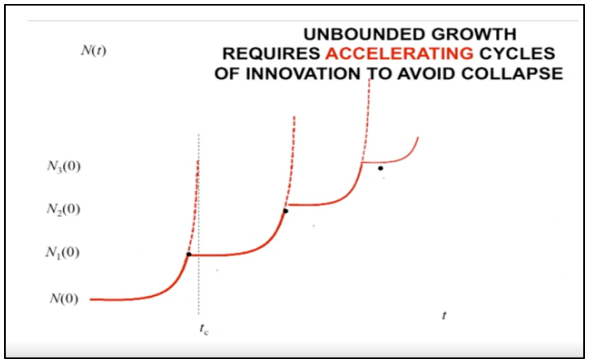
Developing Meta Systems Architectures for Leading Innovation

Executable Architectures for Behavior Validation

- Model Based Systems Engineering



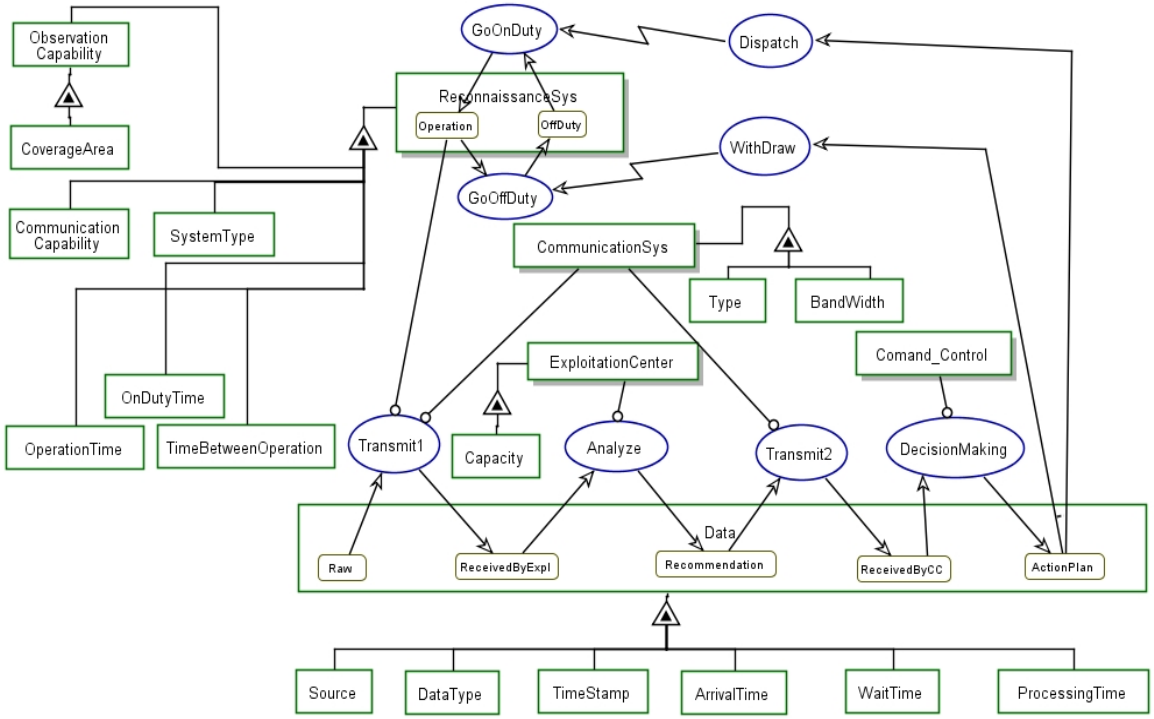
- Model Based Engineering
- Simulation and Modeling



Developing Meta Systems Architectures for Leading Innovation

Executable Architectures for Behavior Validation

The SoS is comprise of four type of systems: Reconnaissance, Communication, Exploitation center, and Command & Control systems



Each system is described by a set of attributes and is associated with some processes that may change the states of other systems

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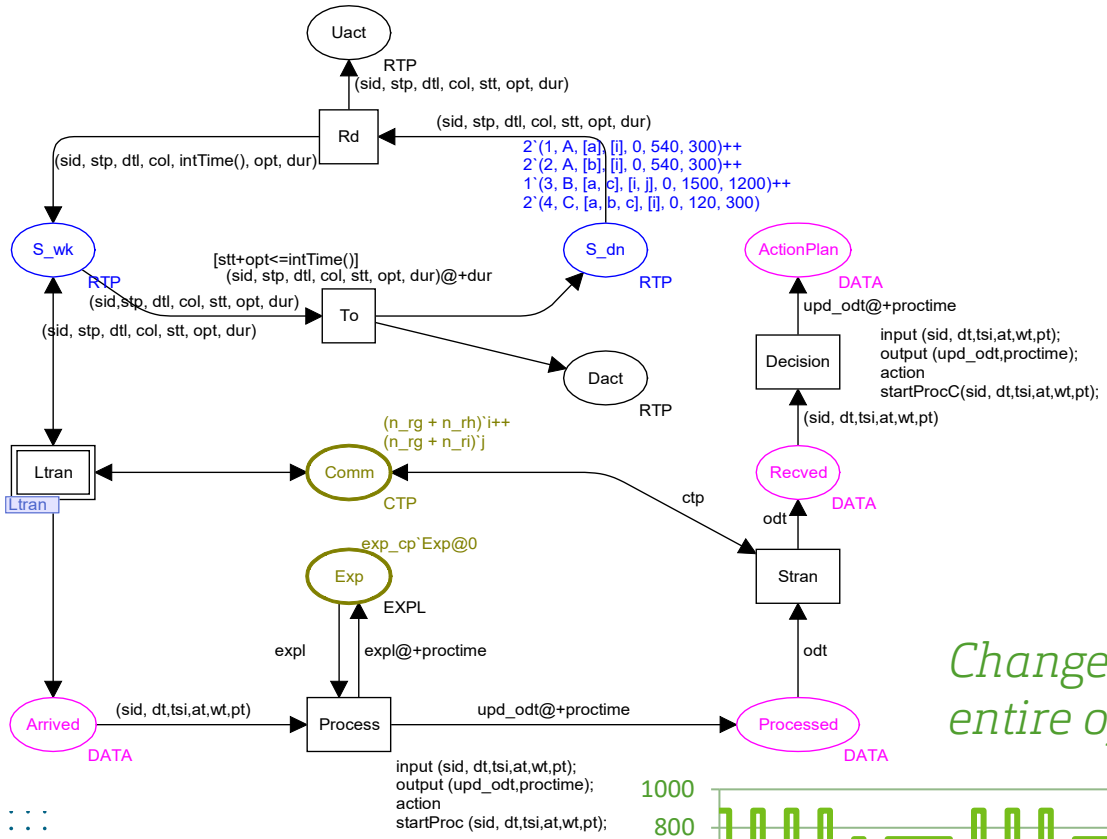
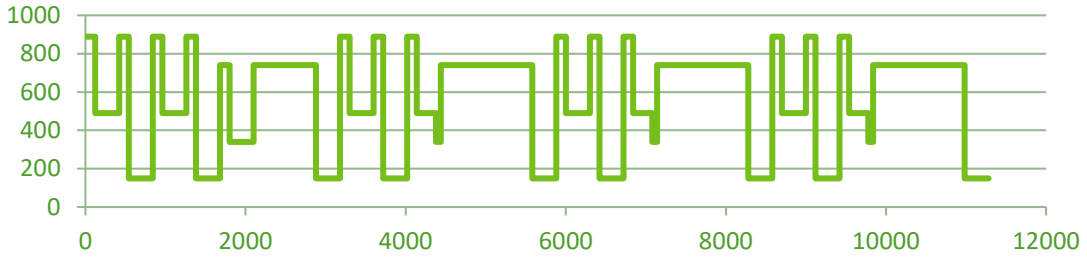
Executable Architectures for Behavior Validation



Changes of coverage area during entire operation period:



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Developing Meta Systems Architectures for Leading Innovation

Executable Architectures for Behavior Validation

- A modeling approach that combines the capabilities of OPM and CPN is proposed to meet this need.
- The OPM specifies the formal system model as it can capture both the structural and the behavioral aspects of a system in a single model.
- The CPN supplements the OPM by providing formal execution semantics.
- The CPN supplements the OPM with state-transition-based execution semantics that support discrete-event system simulations
- The incorporation of CPN also allows the developed system model to be doubled as an analysis model.
- A large collection of analysis methods and tools developed for CPN can be utilized for strong model analysis, verification, and validation.
- Such integration not only avoids the loss of fidelity during model transformation but also eliminates the need to develop a new analysis model when the system model changes.

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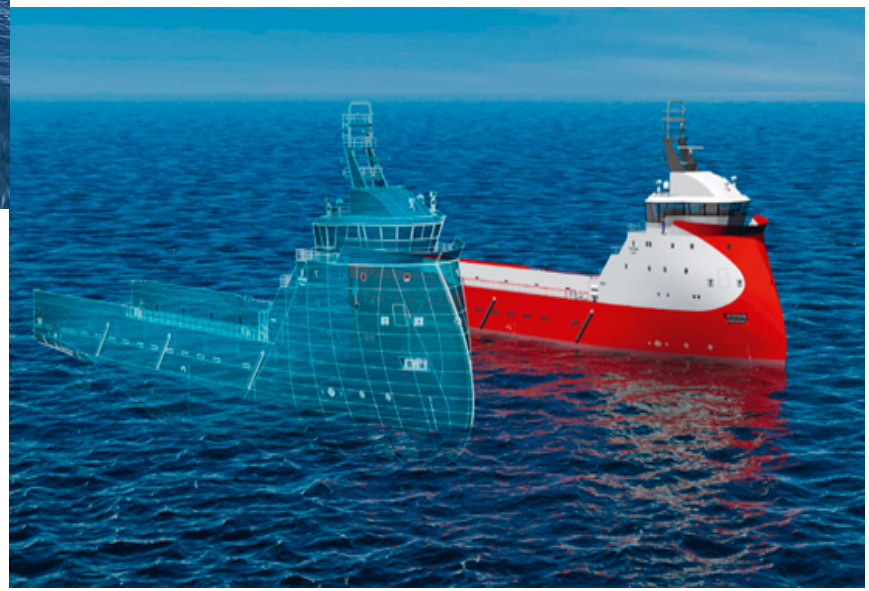
Development of Digital Twins



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Research Needs -Modeling

- Model scarcity along the abstraction hierarchy
- Interaction of software models with multiple physics models
- Modeling to predict emerging behavior
- Compose-able and meta- programmable tools components in
  highly domain specific design tool suites
- Abstractions modularity and composability
- Modeling and systems engineering of rare events

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Research Needs - Autonomy and Adaptation

- Adaptive and hierarchical control
- Deep neural networks in creating adaptive behavior
- Self-organizing systems ensembles
  - Architectures and meta architectures
- Conformance (adaptive systems)
  - Qualification and certification
  - Validation and verification
  - Probabilistic methods in evidence based assurance
  - Validation and testing

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Research Needs - Humans

- Socio-technical aspects
- Interaction between people and technology
- Emerging behavior and human interaction
- Reactive systems

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Research Needs – General Topics

- Safety, security, and privacy integration in design and tools
- Infrastructure (changes and updates)
- Shared open technology with global R&D communities
- Large scale testbeds

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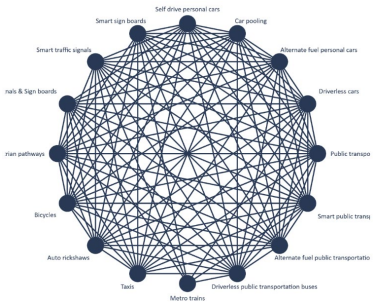
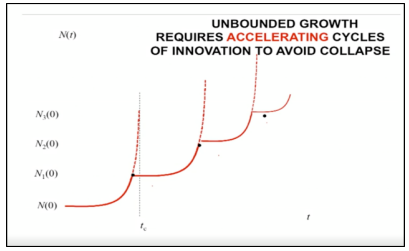
There will be *multi-faceted systems* in different levels of implementation that entail complex logic with many levels of reasoning in intricate arrangement, organized by web of connections and demonstrating self-driven adaptability which are designed for autonomy and exhibiting emergent behavior that can be visualized.



Unbounded growth requires accelerating cycles of innovation to avoid collapse, meta systems architectures and their evolution through innovation in time is essential to survival for us.



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Publications

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