UC San Diego
JACOBS SCHOOL OF ENGINEERING

Convergent Systems Engineering

Jon Wade, Ph.D.
Director of CoSE
December 5, 2020

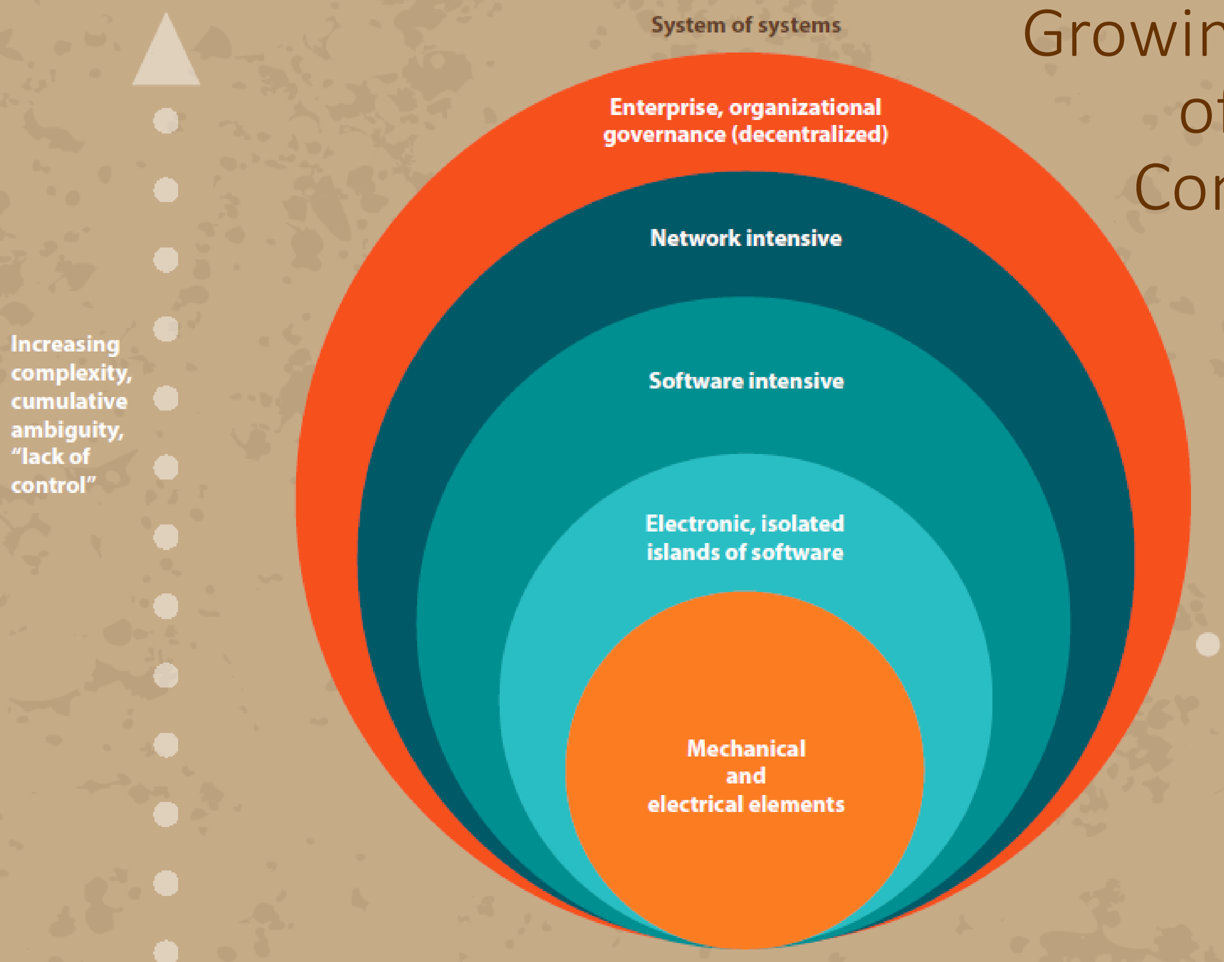
Human needs have hardly changed over the centuries. Societal needs are similar throughout the world, and systems need to respond to such needs.

INCOSE, "INCOSE Systems Engineering Vision 2025.", 2014.

The Major Challenges of the 21st Century

Stephen Hawking's advice "Embrace Complexity"

Growing Levels of System Complexity



Cynefin Framework

Source: INCOSE Vision 2025

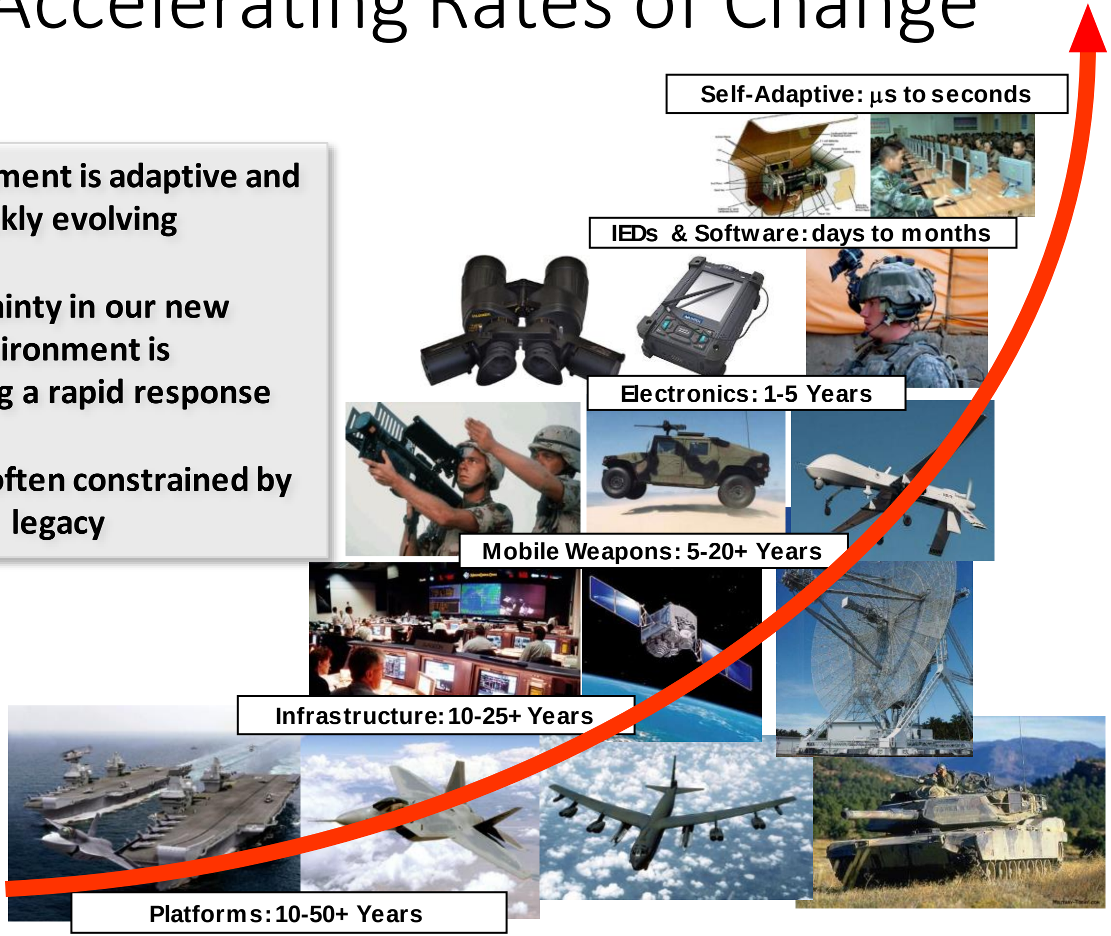
UC San Diego
JACOBS SCHOOL OF ENGINEERING

Accelerating Rates of Change

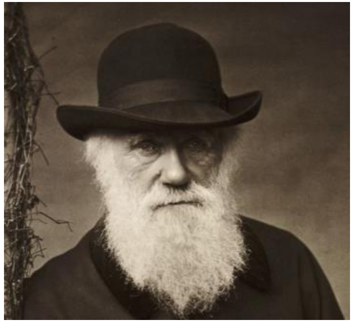
The environment is adaptive and quickly evolving

Uncertainty in our new environment is demanding a rapid response

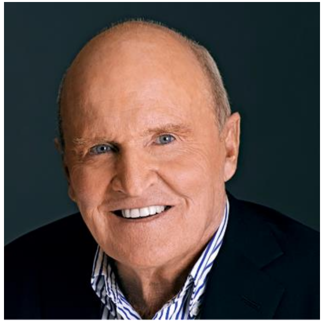
Yet we are often constrained by legacy



Rate of Change



Adaptability is Key to Survival



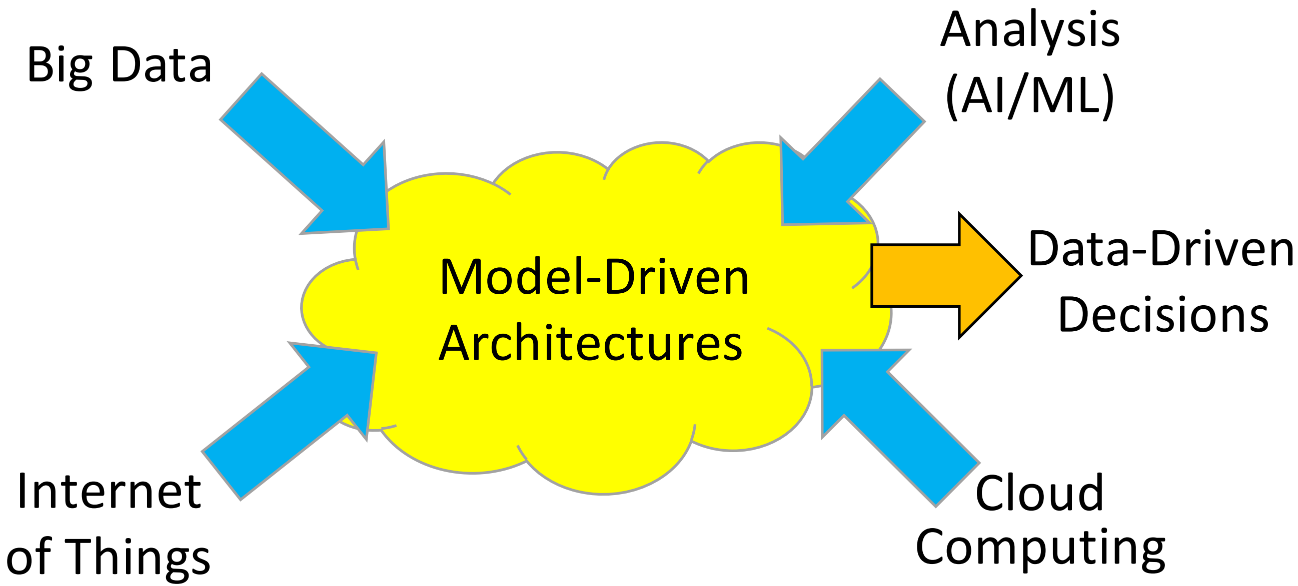
It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change.

– Charles Darwin

If the rate of change on the outside exceeds the rate of change on the inside, the end is near.

– Jack Welch

Digital Convergence

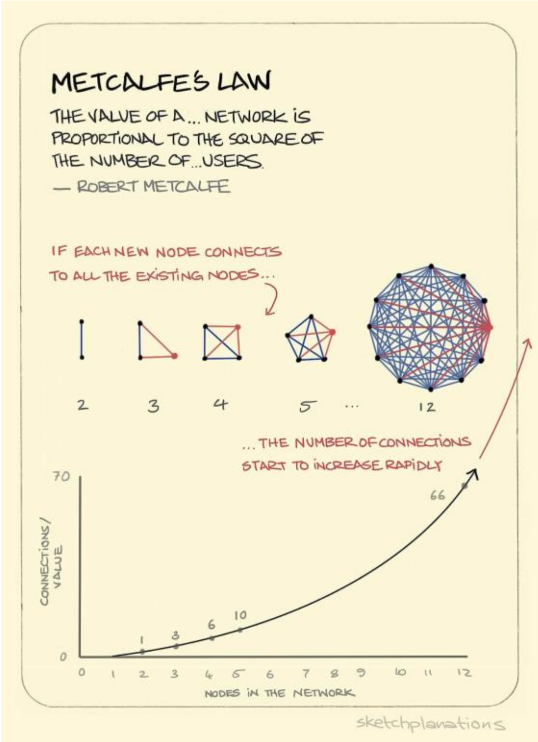


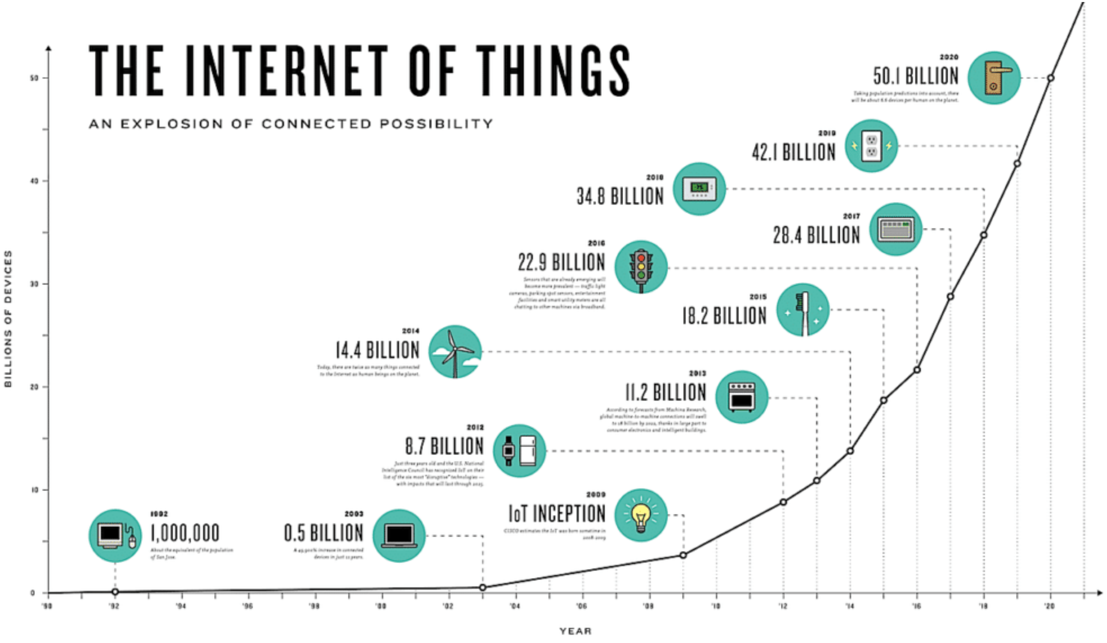
DoD definition of model as 'a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process' (DoD 1998)

Thomas Siebel, "Digital Transformation: Survive and Thrive in an Era of Mass Extinction", 2019.

UC San Diego
JACOBS SCHOOL OF ENGINEERING

The Power of the Network

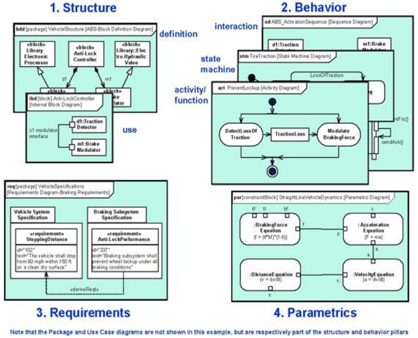


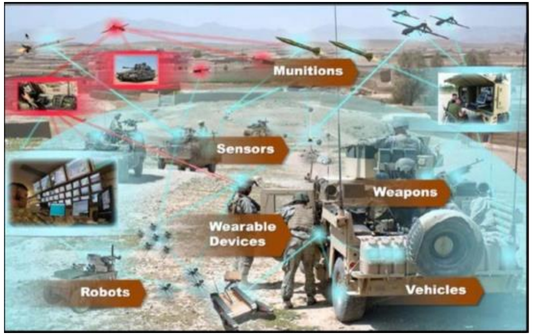


The Power of Digitalization: extracting value from data

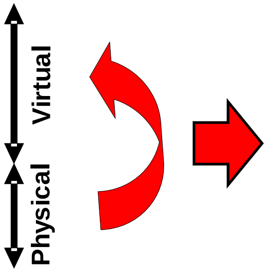
UC San Diego
JACOBS SCHOOL OF ENGINEERING

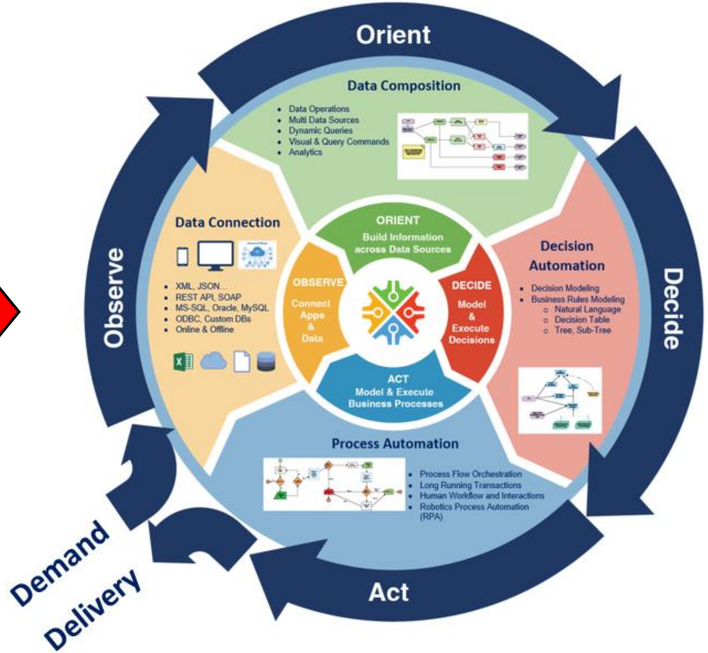
Exploiting the digital power of
computation, visualization and communication
to take better, faster actions





Dynamic System Validation





UC San Diego
JACOBS SCHOOL OF ENGINEERING

Who are the winners in value extraction from data?

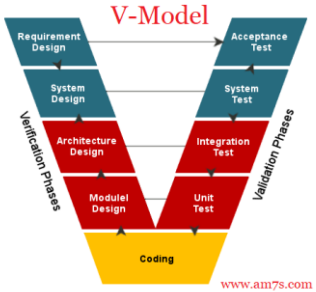
Rank	
1	Apple Inc. 1,576,000
2	Microsoft 1,551,000
3	Amazon.com 1,432,590
4	Alphabet Inc. 979,700
5	Facebook, Inc. 675,690

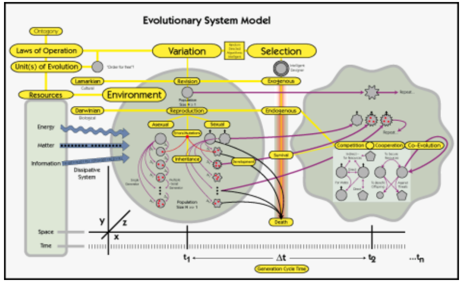
World-wide ranking of public corporations by top market cap

Company	VC ($B)
Tesla Inc TSLA: NASDAQ	$ 257.6
Toyota Motor Corp ... TM: NYSE	$ 205.8
Honda Motor Co Ltd... HMC: NYSE	$ 46.7
Daimler AG DDAIF: NYSE	$ 45.5
General Motors Com... GM: NYSE	$ 36.0
Ford Motor Company F: NYSE	$ 24.3
Nissan Motor Co Lt... NSANY: NASDAQ	$ 15.7

UC San Diego
JACOBS SCHOOL OF ENGINEERING

The Transition





From: Systems Engineering 1.0

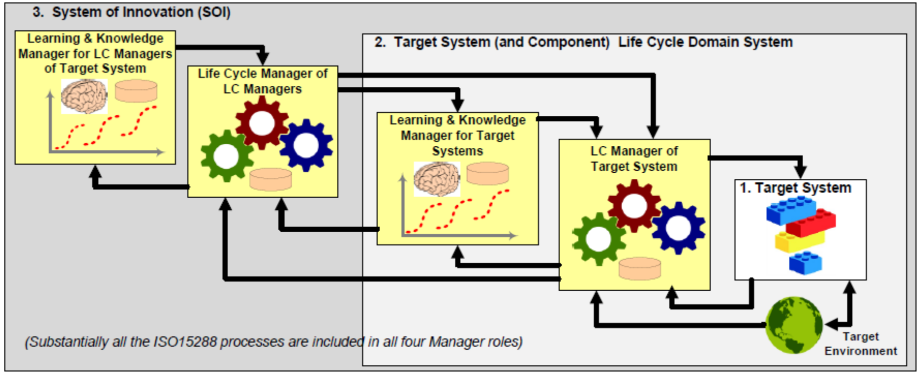
- Systems built to last
- Opinion-based decision making
- Paper-based documentation
- Deeply integrated architectures
- Hierarchical organizational model
- Satisfying the requirements
- Phase-based Verification & Validation

To: Systems Engineering 2.0

- Systems built to evolve
- Model and Data-driven decision making
- Simulation-based documents
- Modularized architectures
- Ecosystem of partners
- Constant experimentation and innovation
- Continuous Verification & Validation

UC San Diego
JACOBS SCHOOL OF ENGINEERING

Agility is Critical: Continuous Learning System Engineering



1. **Agile Software Development** – agile development limited software

2. **Agile System Development** – Entire organization is agile, reducing the risk in any particular interval

3. **Continuous Deployment** – System can be updated at any time, DevOps blurs boundary between development and operations

4. **Systemic Learning** – System is used as an environment to conduct experiments and learn

5. **Continuous Learning System** – System autonomously conducts experiments for system optimizations and/or guides experiment decision-makers and concept designers

Based on Jan Bosch's "Stairway to Heaven"

UC San Diego
JACOBS SCHOOL OF ENGINEERING

INCOSE Response: Systems Engineering

Ends: The ability to create systems that continually evolve to meet their customers' needs under their timelines while being trustworthy, economical and sustainable.

Means:

1. Develop and implement SE Methods, Processes and Tools (MPTs) that are relevant to complex/non-deterministic systems
2. Create expertise of evolving systems (e.g., architectural archetypes) that are appropriate for the domains of interest
3. Ensure that we have a workforce that is capable of applying these MPTs to the systems of interest
4. Broadly apply the systems approach to a broad set of domain areas and scales

UC San Diego
JACOBS SCHOOL OF ENGINEERING

OUR VISION FOR THE FUTURE

We will prepare the next generation of global leaders to channel their passions into driving innovation, fueling economic growth and making our world a better place.

WE MAKE CHANGEMAKERS

Recognized as one of the top 15 research universities worldwide, our culture of collaboration sparks discoveries that advance society and drive economic impact. Everything we do is dedicated to ensuring our students have the opportunity to become changemakers, equipped with the multidisciplinary tools needed to accelerate answers to our world's most pressing issues.

At the University of California San Diego, we prefer the path less traveled. And it has led us to remarkable new ways of seeing and making a difference in the world.

UC San Diego
JACOBS SCHOOL OF ENGINEERING

Convergent Systems Engineering

- *Develop & Educate SE 2.0*
- *Broad Partnerships*,
- *Blurred Boundaries*,
- *Agile Environment*,
- *Community Sharing*.

The essence of Convergent Systems Engineering is to develop meaningful alliances with best-in-class partners from academia, industry and government. These partnerships blur the boundaries between academia and the industry/government reality and foster intellectual breakthroughs that are academic, with the ability to be translated and applied to a wide range of industry initiatives. Outcomes of success are measured and used to improve all areas of performance.

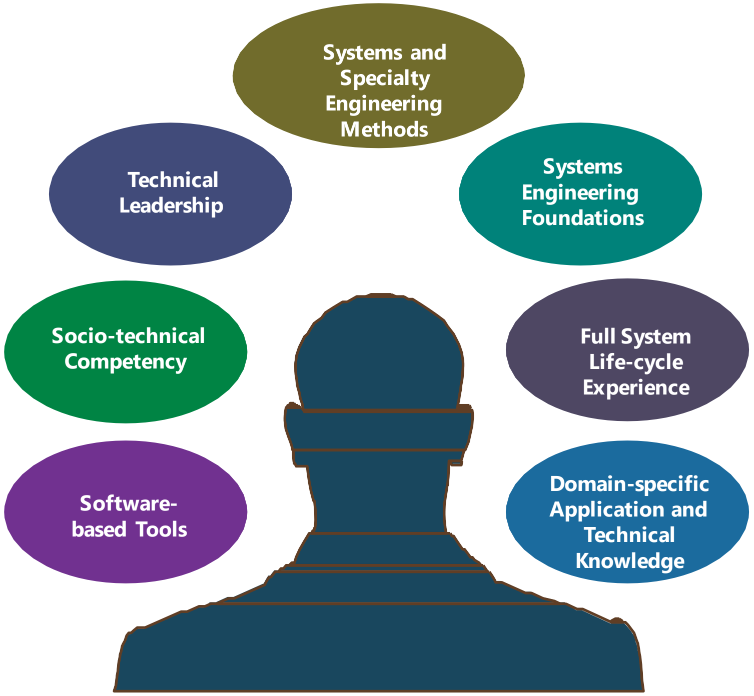
Principles: Convergent engineering has been defined as:

- "A deeply **collaborative, team-based engineering approach**
- for **defining and solving important, complex societal problems**.
- **All necessary disciplines, skills,** and **capabilities** are **brought together**
- to address a **specific research opportunity**.
- It is distinguished by resolutely using **team-research** and **value-creation** best practices
- to **rapidly** and **efficiently integrate** the **unique contributions** of individual members
- and develop **valuable and innovative solutions for society**."

National Academies of Sciences, Engineering and Medicine,
"A New Vision for Center-Based Engineering Research", 2017.

To maximize impact:

- all *leaders* need to be systems thinkers,
- all *engineers* should have systems and systems engineering skills, and
- all *systems engineers* need to be well versed in a broad set of socio-technical and leadership skills, serving as a central, multi-disciplinary focal point for systems development with stakeholders from all walks of life.



INCOSE, "INCOSE Systems Engineering Vision 2025.", 2014.

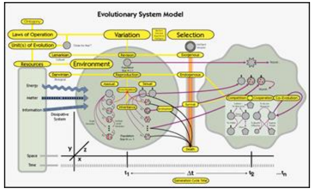
CoSE Major Initiatives

Freshman				Sophomore				Junior				Senior				Graduate				Post-Graduate
Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	
							Coop1				Coop2	Senior Project			Coop3	C1	C4	C7	Coop4	Masters of AESE
Workshops				Workshops				Workshops				SE Lite			Thesis	C2	C5	C8	Thesis	Workshops
																C3	C6	C9		Non-credit courses

	BS
	MS
	MAS/Post-Grad

4. SysEng Masters Program

2. Systems Doctoral Research



3. SysEng 2.0

1. Institute of Convergent Systems Engineering

UC San Diego
JACOBS SCHOOL OF ENGINEERING

CoSE Major Initiatives

Freshman				Sophomore				Junior			
Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr
							Coop1				Coop2
Workshops				Workshops				Workshops			

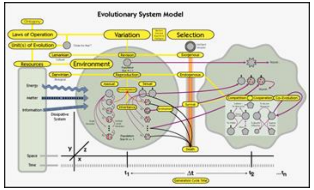
Senior				Graduate				Post-Graduate
Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	
Senior Project			Coop3	C1	C4	C7	Coop4	Masters of AESE
SE Lite			Thesis	C2	C5	C8	Thesis	Workshops
				C3	C6	C9		Non-credit courses

(yellow)	BS
(green)	MS
(blue)	MAS/Post-Grad

5. BS Transdisciplinary Support

4. SysEng Masters Program

2. Systems Doctoral Research



3. SysEng 2.0

1. Institute of Convergent Systems Engineering

UC San Diego
JACOBS SCHOOL OF ENGINEERING

CoSE Major Initiatives

6. BS/MS COOP Program

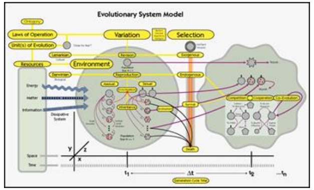
Freshman				Sophomore				Junior				Senior				Graduate				Post-Graduate
Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	
							Coop1				Coop2	Senior Project			Coop3	C1	C4	C7	Coop4	Masters of AESE
Workshops				Workshops				Workshops				SE Lite			Thesis	C2	C5	C8	Thesis	Workshops
																C3	C6	C9		Non-credit courses

	BS
	MS
	MAS/Post-Grad

5. BS Transdisciplinary Support

4. SysEng Masters Program

2. Systems Doctoral Research



3. SysEng 2.0

1. Institute of Convergent Systems Engineering

UC San Diego
JACOBS SCHOOL OF ENGINEERING

CoSE Major Initiatives

6. BS/MS COOP Program

7. Non-Credit Programs

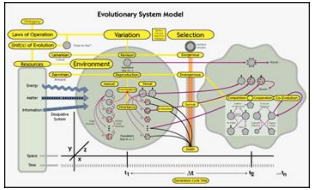
Freshman				Sophomore				Junior				Senior				Graduate				Post-Graduate
Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	
							Coop1				Coop2	Senior Project			Coop3	C1	C4	C7	Coop4	Masters of AESE
Workshops				Workshops				Workshops				SE Lite			Thesis	C2	C5	C8	Thesis	Workshops
																C3	C6	C9		Non-credit courses

	BS
	MS
	MAS/Post-Grad

5. BS Transdisciplinary Support

4. SysEng Masters Program

2. Systems Doctoral Research



3. SysEng 2.0

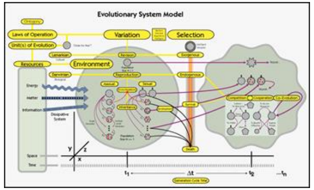
1. Institute of Convergent Systems Engineering

UC San Diego
JACOBS SCHOOL OF ENGINEERING

CoSE Major Initiatives – SE 2.0

Freshman				Sophomore				Junior				Senior				Graduate				Post-Graduate
Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	
							Coop1				Coop2	Senior Project			Coop3	C1	C4	C7	Coop4	Masters of AESE
Workshops				Workshops				Workshops				SE Lite			Thesis	C2	C5	C8	Thesis	Workshops
																C3	C6	C9		Non-credit courses

	BS
	MS
	MAS/Post-Grad



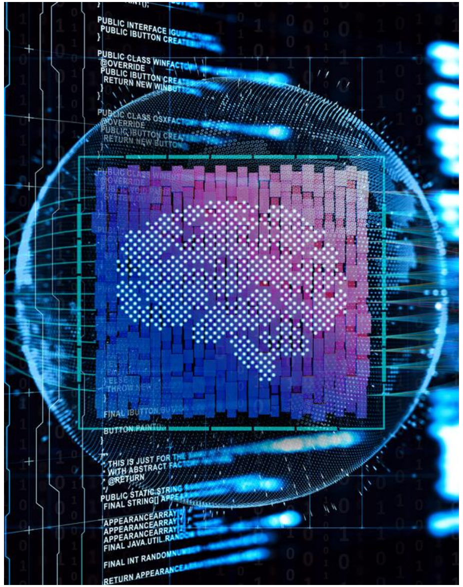
3. SysEng 2.0

UC San Diego
JACOBS SCHOOL OF ENGINEERING

Systems Engineering 2.0 for AI-Intensive Learning Systems

- Systems engineering is ill-prepared for AI-intensive, evolving, learning systems
- It is not possible for everyone to be a AI/ML expert, nor should they be
- New systems abstractions, interfaces, and practices are necessary to address these changes

- **Systems are limited by systems engineering capability, not technology.**



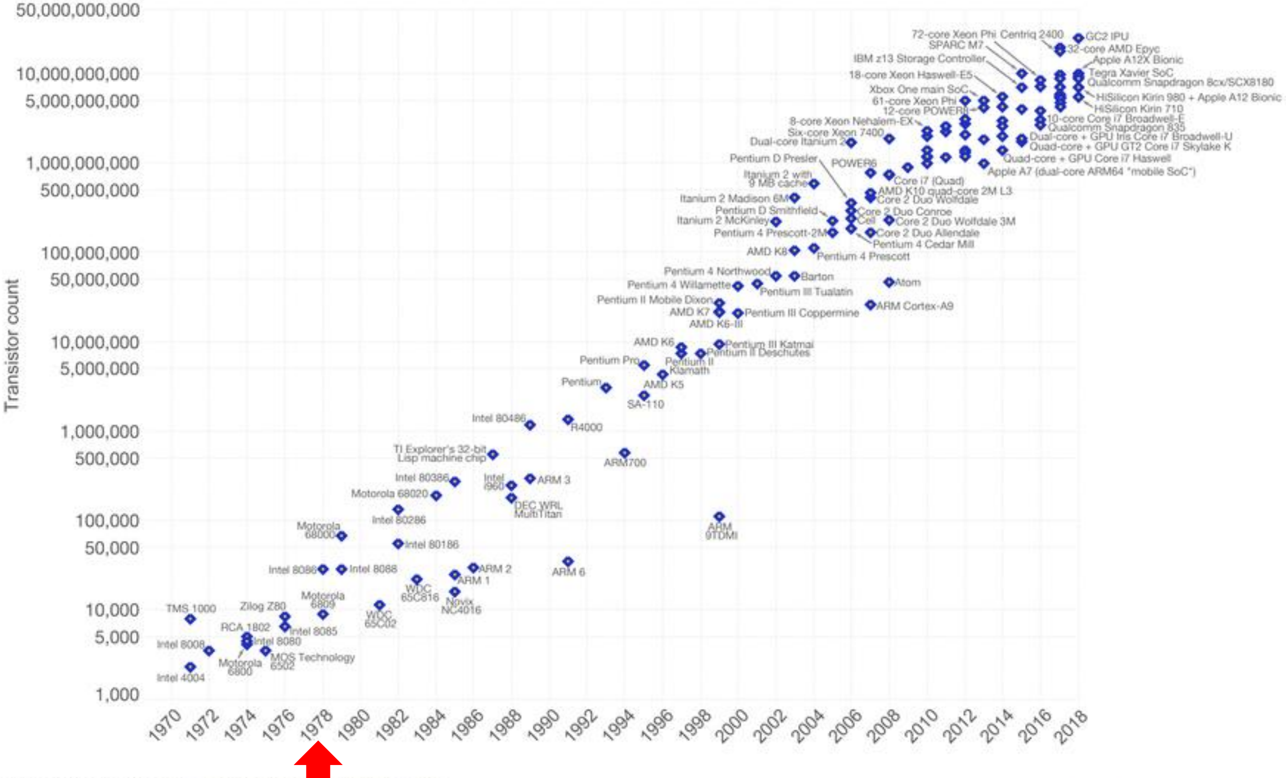
This situation is reminiscent of VLSI systems engineering in the mid-1970s

UC San Diego
JACOBS SCHOOL OF ENGINEERING

Moore's Law – The number of transistors on integrated circuit chips (1971-2018)

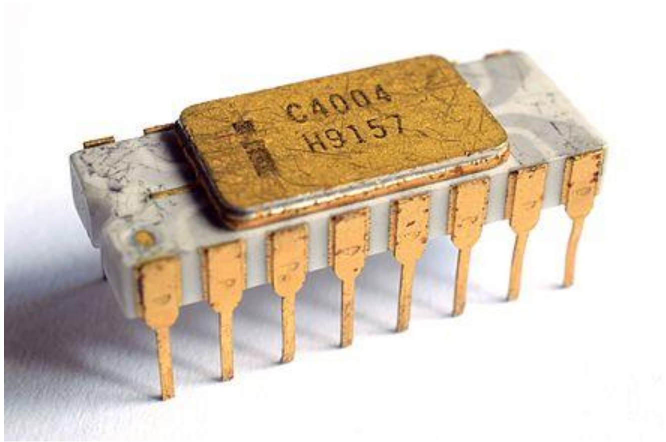
Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are linked to Moore's law.

Our World in Data



UC San Diego
JACOBS SCHOOL OF ENGINEERING

First MicroProcessor Intel 4004



General Info

Launched	late 1971
Discontinued	1981

Performance

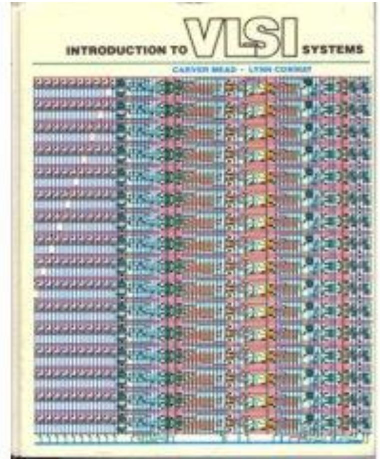
Max. CPU clock rate	740 kHz
Data width	4 bits
Address width	12
RAM	640 bytes
Min. feature size	10 µm
Transistors	2,250
Successor	Intel 4040

While architecturally simple, the 4004 design implementation and fabrication details were obscure to most computer scientists.

According to Lynn Conway, the question back then was ‘‘whether the design of VLSI systems would be possible outside Intel moving forward’’.
VLSI was limited by engineering, not by technology.

The Mead Conway Revolution

- Applications – Software Engineering
- Binary Code – Computer Science
- Architecture – Computer Science
- Logic – Computer Science
- Circuits – Electrical Eng
- Device Models – Electrical Eng
- Device Properties – Device Physics
- Material Properties - Material Science



The Power of Abstraction
For VLSI - 1979

UC San Diego
JACOBS SCHOOL OF ENGINEERING

Mead Conway Impact

Mead & Conway’s methods were suddenly brought forward in 1978–1980 and made visible through a set of courses reaching 120 universities within two years.

Concepts such as simplified design methods, new, electronic representations of digital design data, scalable design rules, ‘‘clean’’ formalized digital interfaces between design and manufacturing, and widely accessible silicon foundries suddenly enabled thousands of chip designers to create tens of thousands of chip designs.

A completely new way of creating VLSI systems on silicon was born.

Moore’s Law was unimpeded by engineering capability.

UC San Diego
JACOBS SCHOOL OF ENGINEERING

Key Lessons from Mead & Conway

"Thirty years later what has remained the same includes:

(1) the importance for interdisciplinary approaches to research and development,

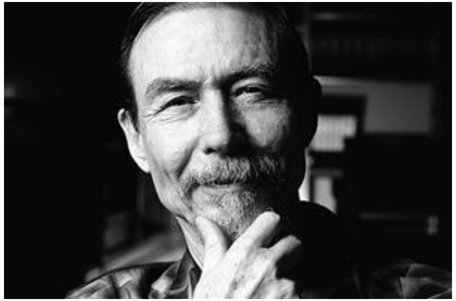
(2) the continuous quest for new vertically-integrated scalable design methodologies, and

(3) the need for open standards and interchange procedures that foster innovation by enabling collaborative engineering across institutions and beyond geographic constraints.

- Prof. Luca Carloni, Columbia University, USA

Panel: The Heritage of Mead & Conway, What Has Remained the Same, What Was Missed, What Has Changed, What Lies Ahead

Lynn Conway



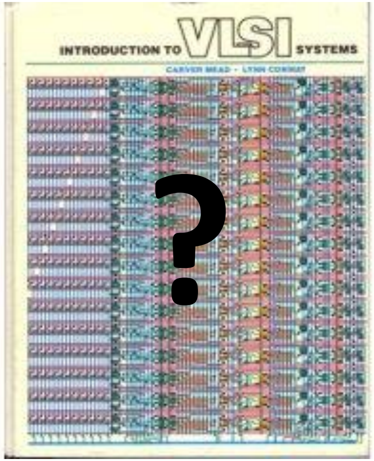
Carver Mead

UC San Diego
JACOBS SCHOOL OF ENGINEERING

The AI-Intensive System Stack

Understanding Value Chain – Systems Thinking
Determining Critical Data – Systems Eng
Collecting Data – Data Science
Engineering Features/Outcomes – Data Science
Setting Up Training Data – AI/CS
Choosing and training Algorithm – AI/CS
Determining HW Platform – Computer Eng
Validating & Deploying AI System – Systems Eng

Closed-Loop Continuous Improvement Systems Engineering



The Power of Abstraction
For AI Systems - 2020

UC San Diego
JACOBS SCHOOL OF ENGINEERING

Future Work

There is much work to be done…

- Develop new vertically-integrated scalable design methodologies
- Define layered abstractions with orthogonalized concerns
- Create open standards and interchange procedures that foster innovation by enabling collaborative multi-disciplinary engineering across institutions and beyond geographic constraints
- Write "the Book"
- Create the courses
- Start the revolution

Thank you, Lynn & Carver!

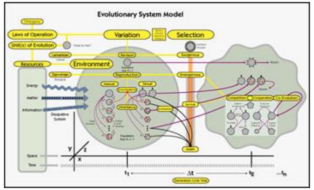
UC San Diego
JACOBS SCHOOL OF ENGINEERING

CoSE Major Initiative: SE Masters Program

Freshman				Sophomore				Junior				Senior				Graduate				Post-Graduate
Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	Fall	Wntr	Sprg	Sumr	
							Coop1				Coop2	Senior Project			Coop3	C1	C4	C7	Coop4	Masters of AESE
Workshops				Workshops				Workshops				SE Lite			Thesis	C2	C5	C8	Thesis	Workshops
																C3	C6	C9		Non-credit courses

(yellow)	BS
(green)	MS
(blue)	MAS/Post-Grad

4. SysEng Masters Program



3. SysEng 2.0

Education Outcomes

- **T-Shaped Practitioners:**
  - **Individualized & Deep:** Able to learn at own pace, using any available materials.
  - **Team Oriented & Broad:** Skilled in leadership, 'followship', communication, listening, negotiation and other soft skills.
- **Innovation and Creativity skills:** Comfortable working in areas of ambiguity, defining the problem and collaboratively creating innovative solutions.
- **Reflection and analytical skills:** Able to reflect on the problem at hand and apply effective data-driven and analytic approaches. Capable of learning from the past and anticipating the future.
- **Social Skills and Awareness:** Engineering as an ethical decision-makers, able to work effectively in teams, communicate with multiple audiences, and immerse themselves in public policy debates and will need to do so more effectively in the future.
- **Context and Lifecycle skills:** Able to operate with contextual awareness, as a critical principle, including the system and life-cycle state, domain and system, and the balance between opposing system properties.

Masters of Science in SysEng degree

- Focused on educating students to be leaders in SE 2.0 while advancing the state of the art
- Masters of Science, conforming with UCSD/UC requirements
    - Thesis Plan with course and research requirements
    - Exam Plan through Capstone experience
    - 3 quarters, 6 units/quarter residency
- 6 Core System Engineering courses with 3 additional courses in concentrations plus Thesis/Capstone
- State-funded
- Achievable in one year Full-time, 2 years + 1 summer Part-Time

UC San Diego
JACOBS SCHOOL OF ENGINEERING

MAE Systems Engineering Degrees

	MS of Systems Engineering		MAS of Architecture-Based Enterprise SE
Specialization	Modeling & Data Analytics	Cyber-Physical Human Systems	N/A
Focus	System Phenomenon	Products & Services	Enterprise
Exam/Thesis	Yes/Yes		Yes/No
Courses	6 Core, 3 Concentration, Thesis/Capstone		9 Core, Capstone
Fulltime/ Part-time	Yes (1-year)/Yes (2-years)		Yes (1 year)/No
Hybrid	No		Yes
Students	All*		Professional
Funding	State		Self

* Competence is required in statistics/probability, programming & AI/ML. An online short-course will be created for this.

INCOSE Competency Framework

Understand

CORE COMPETENCIES

Core competencies underpin engineering as well as systems engineering.

Systems Thinking	The application of the fundamental concepts of systems thinking to systems engineering;
Lifecycles	Selection of the appropriate lifecycles in the realization of a system;
Capability Engineering	An appreciation of the role the system of interest plays in the system of which it is a part;
General Engineering	Foundational concepts in mathematics, science and engineering and their application;
Critical Thinking	The objective analysis and evaluation of a topic in order to form a judgement;
Systems Modeling and Analysis	Provision of rigorous data and information including the use of modeling to support technical understanding and decision making.

Lead

PROFESSIONAL COMPETENCIES

Behavioral competencies well-established within the Human Resources (HR) domain. To facilitate alignment with existing HR frameworks, where practicable, competency definitions have been taken from well-established, internationally-recognized definitions rather than partial or complete re-invention by INCOSE.

Communications	The dynamic process of transmitting or exchanging information;
Ethics and Professionalism	The personal, organizational, and corporate standards of behavior expected of systems engineers;
Technical Leadership	The application of technical knowledge and experience in systems engineering together with appropriate professional competencies;
Negotiation	Dialogue between two or more parties intended to reach a beneficial outcome where difference exist between them;
Team Dynamics	The unconscious, psychological forces that influence the direction of a team's behavior and performance;
Facilitation	The act of helping others to deal with a process, solve a problem, or reach a goal without getting directly getting involved;
Emotional Intelligence	The ability to monitor one's own and others' feelings and use this information to guide thinking and action;
Coaching and Mentoring	Development approaches based on the use of one-to-one conversations to enhance an individual's skills, knowledge or work performance.

Realize

MANAGEMENT COMPETENCIES

The ability to perform tasks associated with controlling and managing Systems Engineering activities. This includes tasks associated with the Management Processes identified in the INCOSE SE Handbook.

Planning	Producing, coordinating and maintaining effective and workable plans across multiple disciplines;
Monitoring and Control	Assessment of an ongoing project to see if the current plans are aligned and feasible;
Decision Management	The structured, analytical framework for objectively identifying, characterizing and evaluating a set of alternatives;
Concurrent Engineering	A work methodology based on the parallelization of tasks;
Business and Enterprise Integration	The consideration of needs and requirements of other internal stakeholders as part of the system development;
Acquisition and Supply	Obtaining or providing a product or service in accordance with requirements;
Information Management	Addresses activities associated with all aspects of information, to provide designated stakeholders with appropriate levels of timeliness, accuracy and security;
Configuration Management	Ensuring the overall coherence of system functional, performance and physical characteristics throughout its lifecycle;
Risk and Opportunity Management	The identification and reduction in the probability of uncertain events, or maximizing the potential of opportunities provided by them,

Design

TECHNICAL COMPETENCIES

The ability to perform tasks associated primarily with the suite of Technical Processes identified in the INCOSE SE Handbook.

Requirements Definition	To analyze the stakeholder needs and expectations to establish the requirements for a system;
System Architecting	The definition of the system structure, interfaces and associated derived requirements to produce a solution that can be implemented;
Design for…	Ensuring that the requirements of all lifecycle stages are addressed at the correct point in the system design;
Integration	The logical process for assembling a set of system elements and aggregates into the realized system, product or service;
Interfaces	The identification, definition and control of interactions across system or system element boundaries;
Verification	A formal process of obtaining objective evidence that a system fulfils its specified requirements and characteristics;
Validation	A formal process of obtaining objective evidence that the system achieves its intended use in its intended operational environment;
Transition	Integration of a verified system into its operational environment including the wider system of which it forms a part;
Operation and Support	When the system is used to deliver its capabilities, and is sustained over its lifetime.

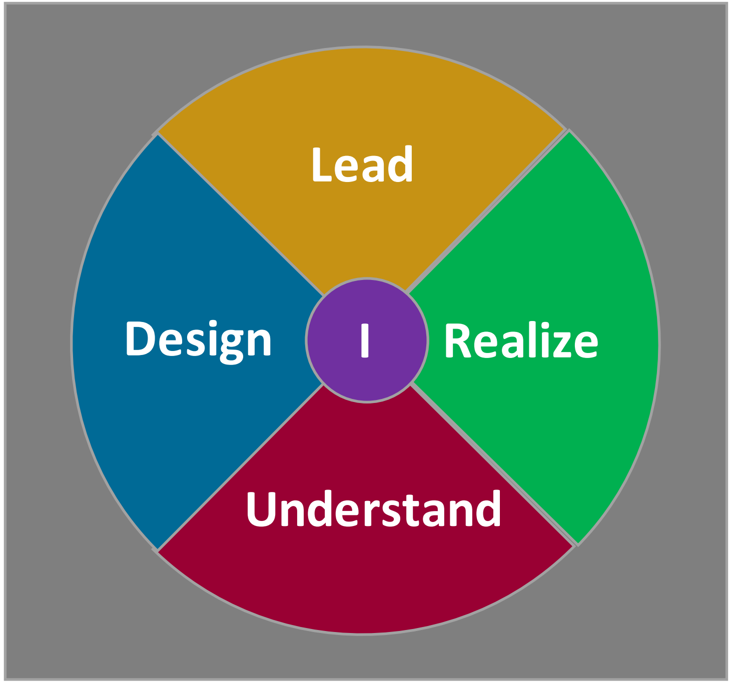
INTEGRATING COMPETENCIES

This competency group recognizes Systems Engineering as an integrating discipline, joining activities and thinking from specialists in other disciplines to create a coherent whole.

Project Management	Identification, planning and coordinating activities to deliver a satisfactory system, product, service of appropriate quality;
Finance	Estimating and tracking costs associated with the project;
Logistics	The support and sustainment of a product once it is transitioned to the end user;
Quality	Achieving customer satisfaction through the control of key product characteristics.

UC San Diego
JACOBS SCHOOL OF ENGINEERING

MS Curriculum



Areas	Topics	Modeling & Data Analytics	Cyber-Physical Human Systems
Lead	Self, Team, Vision, Communication	**Teamship**	
Understand	Abstract, Model, Experiment, Analyze	**Modeling & Simulation**	
		Human/Machine Analysis & Decision-Making	
Design	Conceive, Architect, Implement, Evolve	**System Conception**	
Realize	Business Fundamentals,Lifecycle Management, Monitoring & Control	**Intra/Entrepreneurship**	
		Mgmt of Complex Systems	
Specialize		***Architectural/Systems Modeling***	***System Architecture & Design - CPHS***
		MDA 2	***System Implementation - CPHS***
		MDA 2	***System Evolution - CPHS***
Integrate	Understand, Use Conventional Practice Use and Expand State of the Art	**Capstone Exam**	
		MS Thesis	

UC San Diego
JACOBS SCHOOL OF ENGINEERING

Education as Living Research Lab

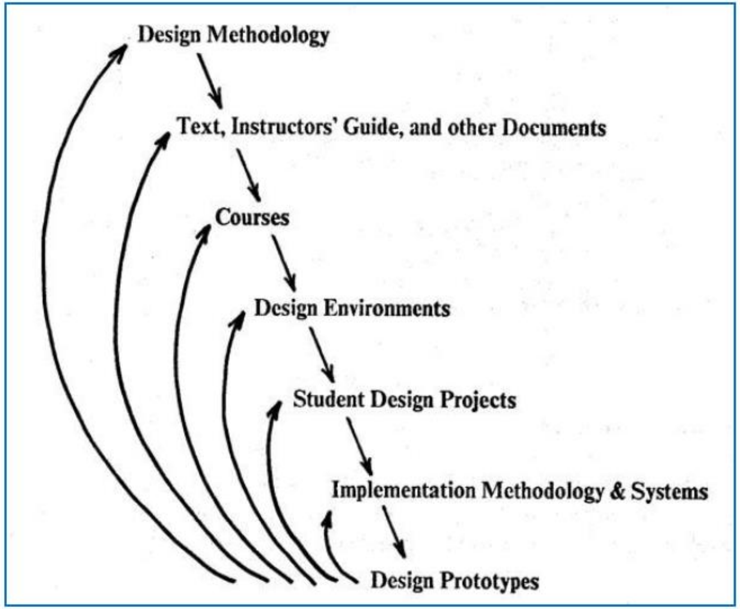
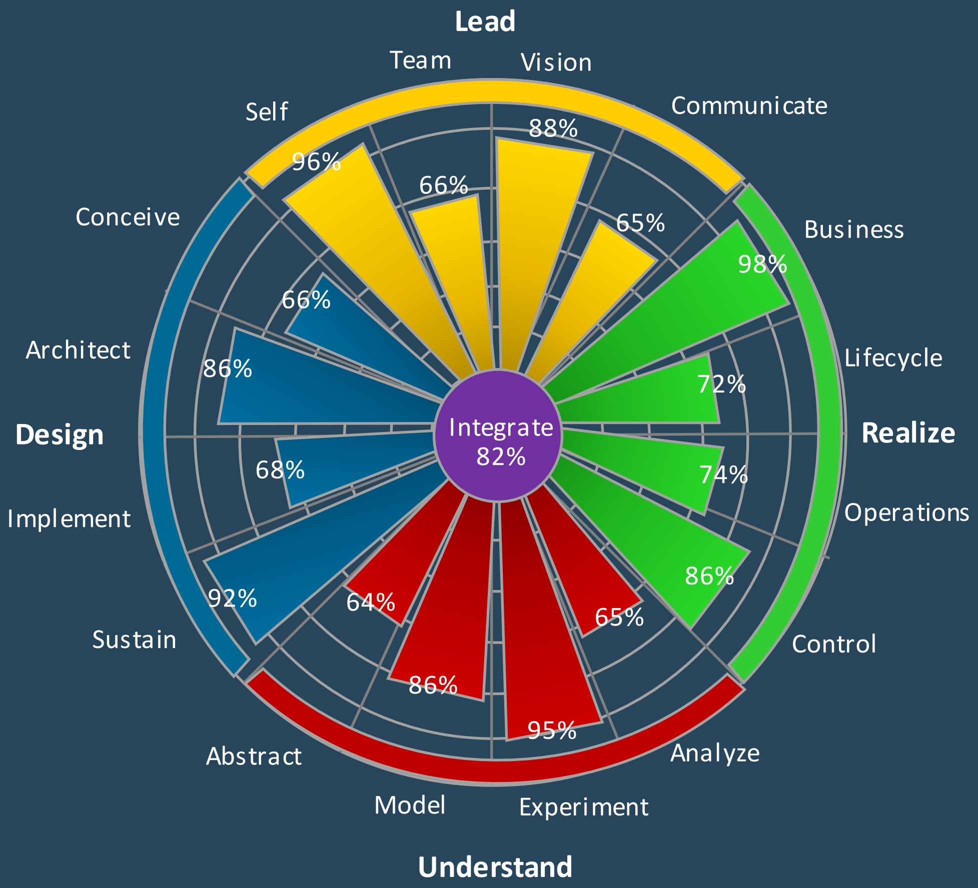


FIGURE 17: The evolution of a multi-level system of knowledge: design projects provide feedback for debugging at all levels [28].

Lynn Conway, MPC Adventures: Experiences with the Generation of VLSI Design and Implementation Methodologies, 1981.



Example Profile – for reference only

Systems Engineering Education Ecosystem

Problem: The lack of an overall SE academic community coupled with a consistent view of SE in practice has resulted in the lack of coherence in curriculum and educational programs which has impacted SE education's ability to meet the rapidly changing needs of its practitioners, threatening SE with a lack of relevance.

Solution: The SEEE team is dedicated to creating a collaborative ecosystem in which systems engineering educators can interact with SE employer partners and students to define, create and exchange curricular and pedagogical resources to enhance educational impact.


Thank You!

UC San Diego
JACOBS SCHOOL OF ENGINEERING

Discussion