26th annual INCOSE international symposium
Edinburgh, UK
July 18 - 21, 2016

Beauty as a Guiding Principle in Systems Engineering

Kevin Devaney
SRC, Inc.
Finger Lakes Chapter

Agenda

- Background
- Examples where beauty matters
- Beauty as a guiding principle
- Applications to systems engineering
- Conclusions

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Integral Theory

- Integral Theory
  - School of philosophy founded by Ken Wilber
  - Integrate all human knowledge into a single framework
  - Applied to over 35 domains
- Integral Theory models are useful for SE
  - Broaden the perspective of SE
  - Improve how SE is practiced
  - Develop better solutions

Ken Wilber

Integral Theory Models

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	Interior	Exterior
Individual	Upper Left (UL) I Intentional (Subjective)	Upper Right (UR) IT Behavioral (Objective)
Collective	Lower Left (LL) WE Cultural (Intersubjective)	Lower Right (LR) ITS Social (Interobjective)

Four Quadrant Model

Level	Color	Perspective
Post Integral	Turquoise	Kosmocentric
Integral	Teal	Planetcentric
Post Modern	Green	Worldcentric
Modern	Orange	Sociocentric
Traditional	Amber	Ethnocentric
Tribal	Red	Egocentric

Levels of Development Model

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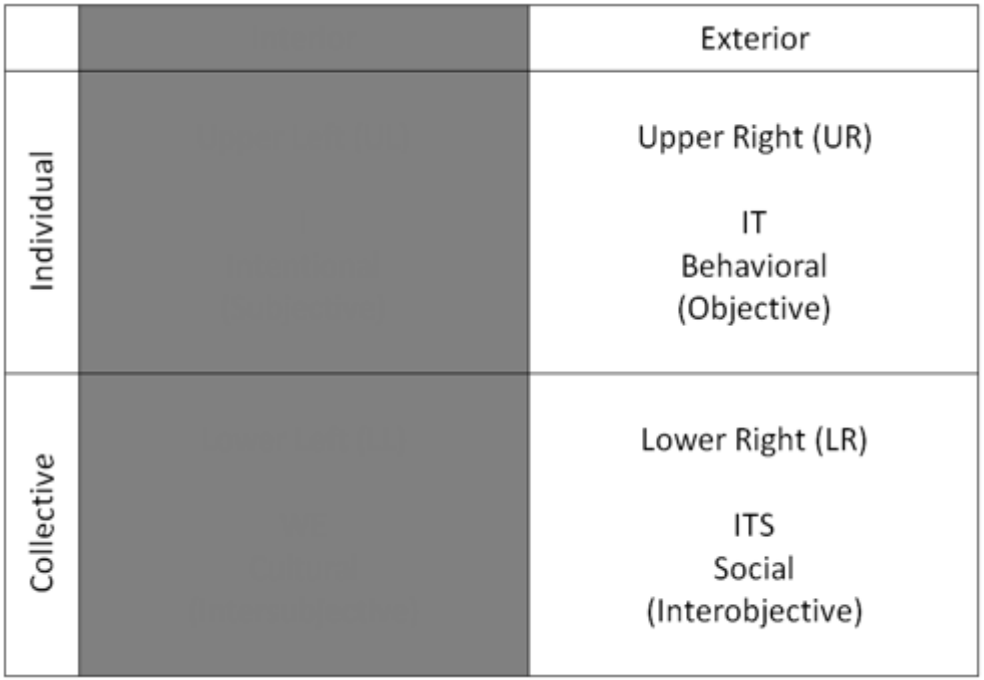
Integral View of Systems Engineering



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Use All Four Quadrants

	Interior	Exterior
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Levels of Development Model

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- Mankind moving to higher levels of consciousness or development
- Moving up - increasing perspective and decreasing egocentrism

Levels of Development Model

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- Technical organizations tend to be at the Modern/Orange level
  - Scientific/rational approach
  - Use just right-hand quadrants

Technical Organizations in Model

Level	Color	Perspective
Post Integral	Turquoise	Kosmocentric
Integral	Teal	Planetcentric
Post Modern	Green	Worldcentric
Modern	Orange	Sociocentric
Traditional	Amber	Ethnocentric
Tribal	Red	Egocentric

- Higher performance is possible at Integral/Teal level
  - Make use of all four quadrants – objective and subjective

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Energy-Efficient Buildings

		Exterior
Individual		Upper Right (UR) IT Behavioral (Objective)
Collective		Lower Right (LR) ITS Social (Interobjective)

Solar Decathlon Building

- Dr. Mark DeKay, *Integral Sustainable Design (2011)*
- Energy efficient / LEED-certified buildings
  - Emphasis on the technical aspects
  - Ignore subjective aspects (e.g. beauty)

Integral Sustainable Design

	Interior	Exterior
Individual	I - Perspective of Experiences Shape Form to Engender Experience - Beauty and aesthetics - Experience of nature's cycles, processes, forces	IT - Perspective of Behaviors Shape Form to Maximize Performance - Energy, water, materials efficiency - LEED rating system
Collective	WE - Perspective of Culture Shape Form to Manifest Meaning - Connection to nature - Local myths & rituals	ITS – Perspective of Systems Shape Form to Guide Flow - Fitness to site & context

Solar Umbrella House

- Use all four quadrants
  - Include subjective aspects of design
  - Include beauty, culture, connection with nature
  - Not only save energy, but instill environmental values

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Using All Four Quadrants

	Interior	Exterior
Individual	I - Perspective of Experiences Shape Form to Engender Experience - Beauty and aesthetics - Experience of nature's cycles, processes, forces	IT - Perspective of Behaviors Shape Form to Maximize Performance - Energy, water, materials efficiency - LEED rating system
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Joint Strike Fighter

X-32

X-35

X-32 Photo credit: US Air Force Public domain
X-35 Photo credit: US Navy / Public domain

X-32

Photo credit: US Air Force / Public domain

Aesthetic Usability Bias

- Aesthetic designs
  - Are perceived as easier to use
  - Foster more positive attitudes
  - Have a higher degree of acceptance
  - Make people more tolerant of design flaws
  - Promote feelings of affection and loyalty

Macintosh Computer

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Beauty as a Guiding Principle

"In fundamental physics, a beautiful or elegant theory is more likely to be right than a theory that is inelegant"
– Murray Gell-Mann

Murray Gell-Mann

Beauty in Science and Nature

- Another physicist and Noble Prize winner, Frank Wilczek
- *A Beautiful Question: Finding Nature's Deep Design (2015)*

Frank Wilczek

Photo credit: Amity Wilczek / Permission of Frank Wilzcek

A Beautiful Question

- Does the world embody beautiful ideas?
- Is the world a work of art?
- Is the physical world, considered as a work of art, beautiful?

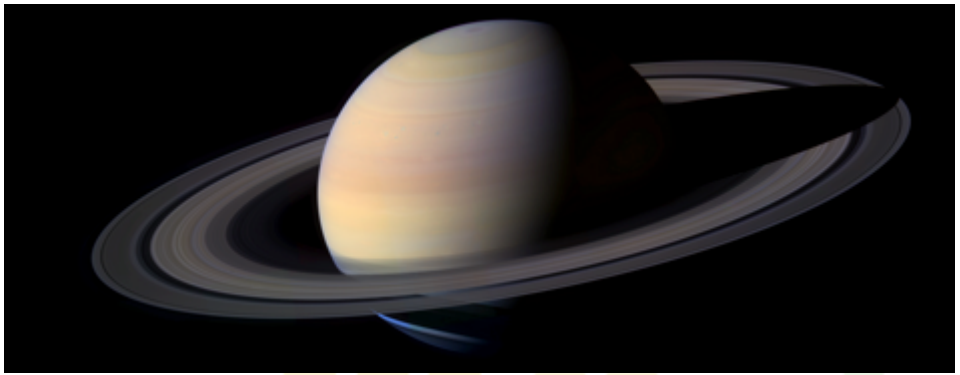


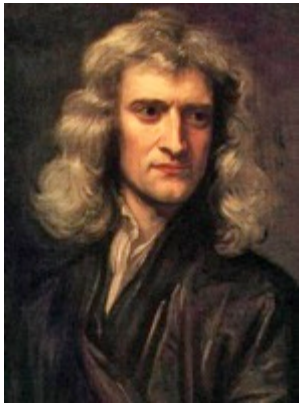
Photo credit: NASA/ Public domain

A Beautiful Question

- Many great scientists in history used beauty as a guiding principle in their research

Pythagoras

Kepler



Newton

Three Examples

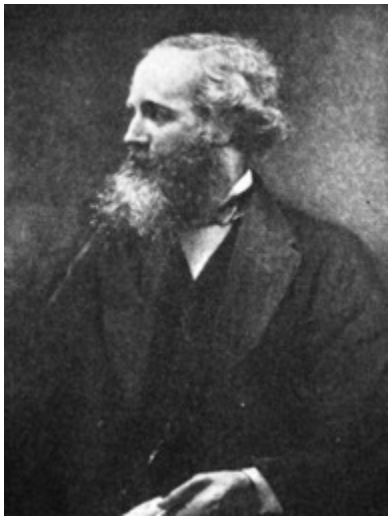
Scientist	Areas of Interest	Comments
Pythagoras	Math Music	All things are number Relationships between numbers and harmony
Kepler	Planetary orbits	Use Platonic solids to model planetary orbits
Newton	Laws of motion Light and color	Dynamical beauty Analysis and synthesis

Search for Beauty – Driven by Faith

"For all these searchers, finding beauty embodied in the physical world, reflecting God's glory, was the goal of their search.
It inspired their work, and sanctified their curiosity.
And with their discoveries, their faith was rewarded."
- A Beautiful Question

Maxwell's Equations

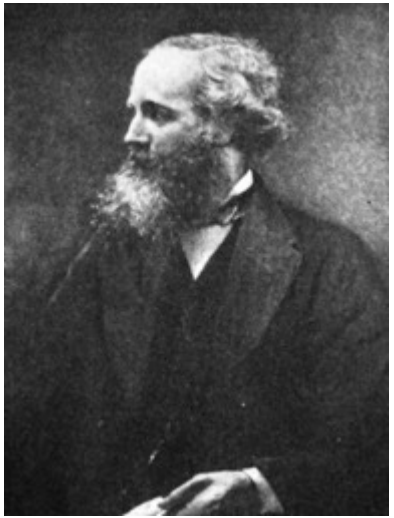
- Good example of how beautiful ideas are embedded in nature
  - Beauty as a tool
  - Beauty as an experience
  - Beauty and symmetry



James Clerk Maxwell

Maxwell – Beauty as a Tool

- Maxwell's primary tools were imagination and play, guided by a sense of mathematical beauty
- He showed that these tools work



James Clerk Maxwell

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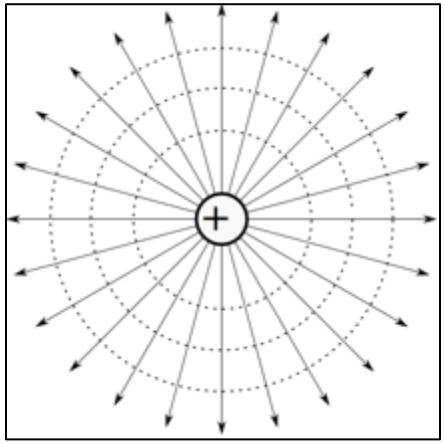
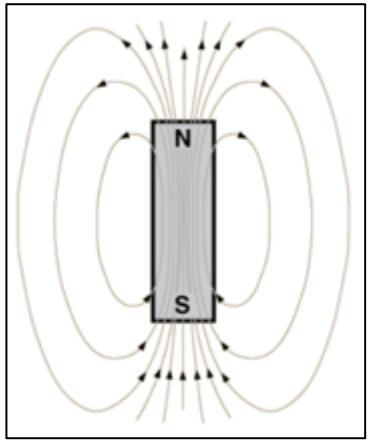
Maxwell – Beauty as an Experience

– The equations can be expressed pictorially, in terms of flows



Electric Field



Magnetic Field

Maxwell – Beauty as an Experience

– The equations themselves are beautiful –
one would be disappointed if they were wrong

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

Maxwell's Equations

Maxwell – Beauty and Symmetry

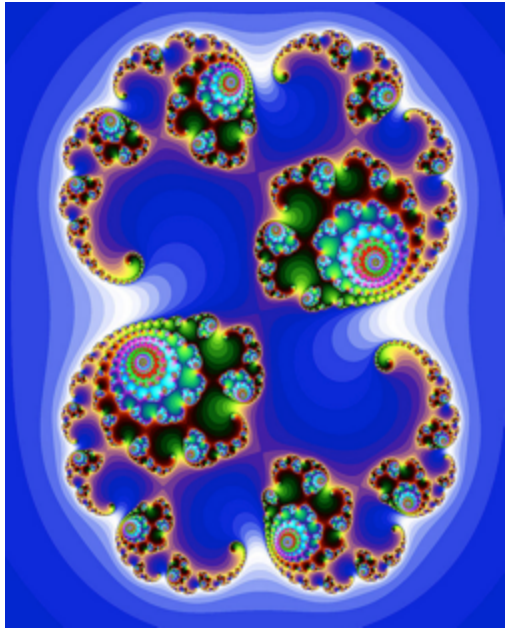
- Over time, we have developed a deeper appreciation for their beauty, symmetry
- Equations can have symmetry,
  (not just for objects)

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

Maxwell's Equations

Nature's Artistic Style

- Symmetry
  - A love of harmony, balance, and proportion
- Economy
  - Satisfaction in producing an abundance of effects from very limited means



A Fractal Pattern

A Beautiful Question

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- Is the world a work of art?
- Is the physical world, considered as a work of art, beautiful?

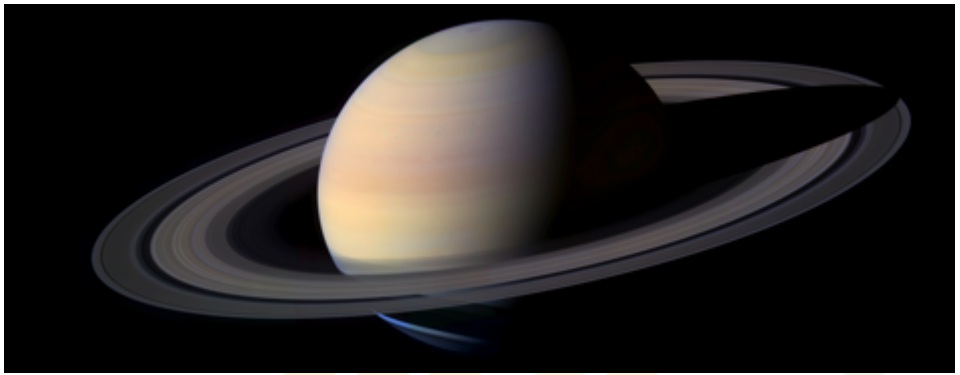
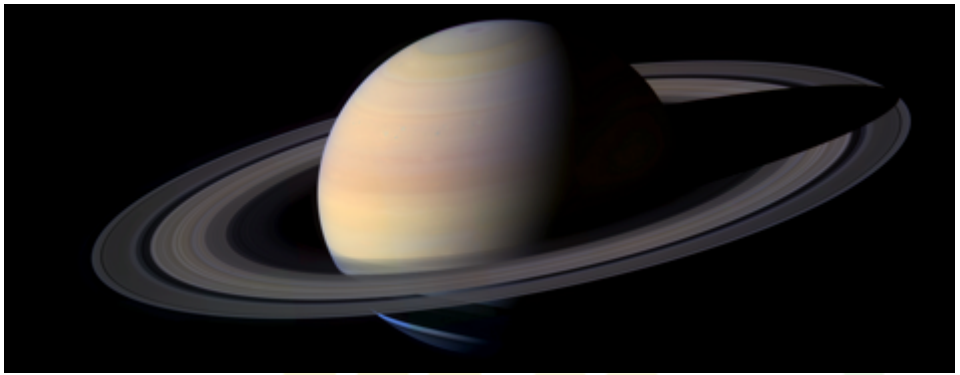


Photo credit: NASA/ Public domain

A Beautiful Question

- Does the world embody beautiful ideas? – Yes!
- Is the world a work of art? – Yes!
- Is the physical world, considered as a work of art, beautiful? – Yes!



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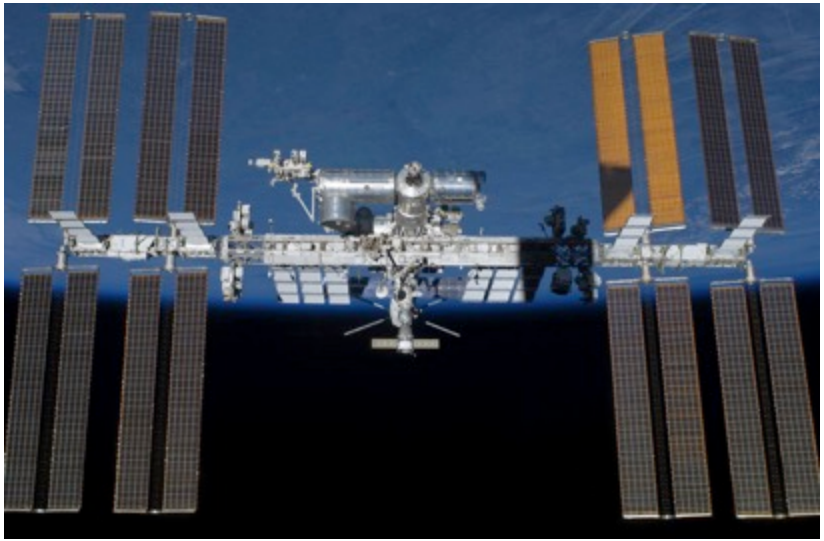
Beauty as a Guide for SE

- Beauty is a useful guiding principle in science and mathematics
- Engineering is the application of science and mathematics
- Beauty is also a useful guiding principle for systems engineering
- How could we apply that idea?

Tour Guide

System Architecture

- System architecture is an art
- Book: *The Art of System Architecting* (Meier, Rechtin)
  - Quote: “The practice of architecting…
    it is process of insights, vision, intuitions, judgment calls, and even taste.”
- Beauty therefore a useful guiding principle

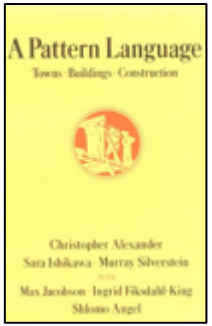


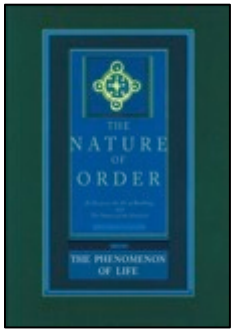
International Space Station

Photo credit: NASA / Public domain

Christopher Alexander

- Studied beauty in architecture (buildings and cities)
- Books:
  - *A Pattern Language*
    (Basis for software design patterns)
  - *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe*
    (Study of the elements of beauty in architecture)





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Beauty – 15 Properties

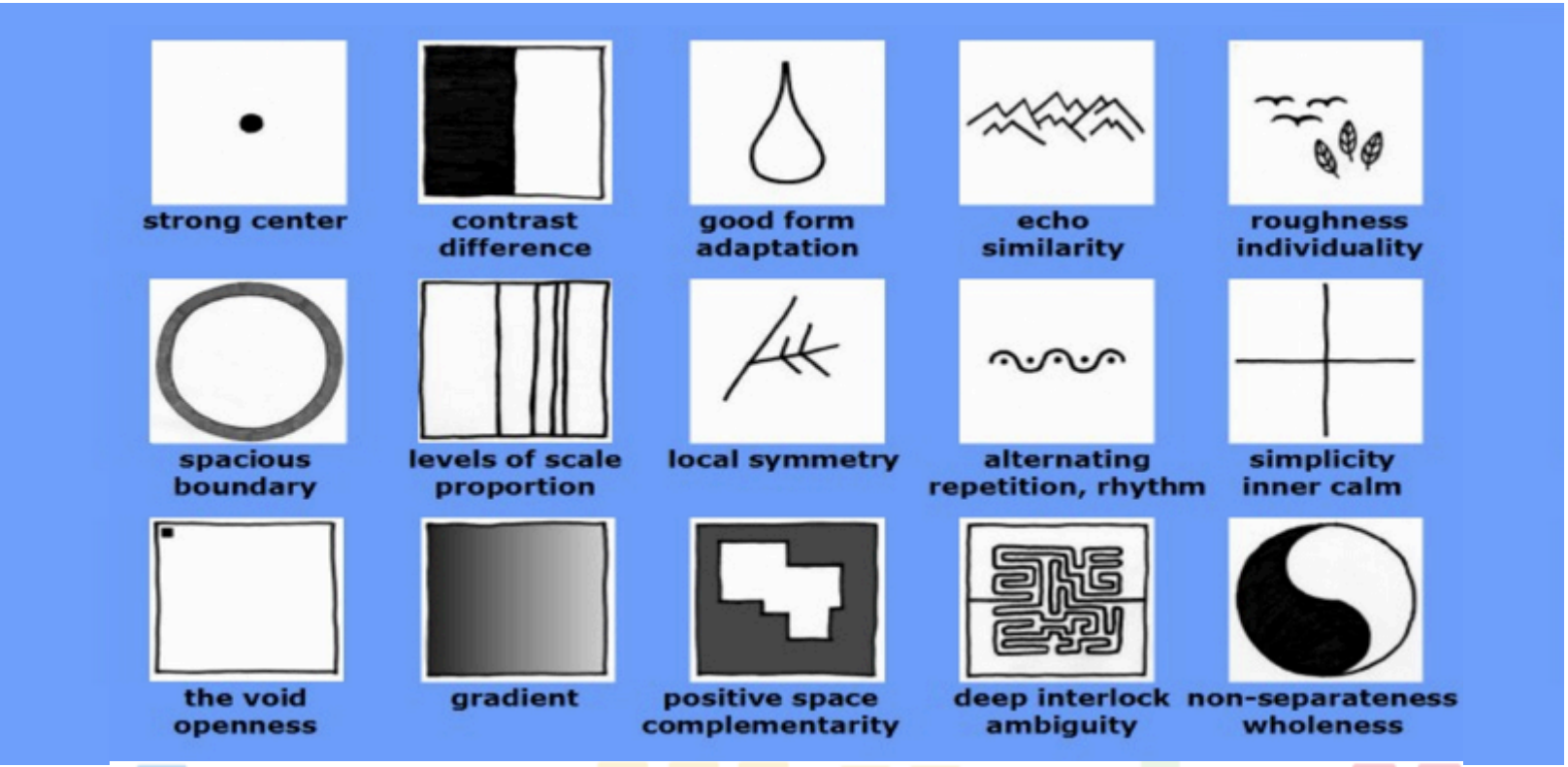

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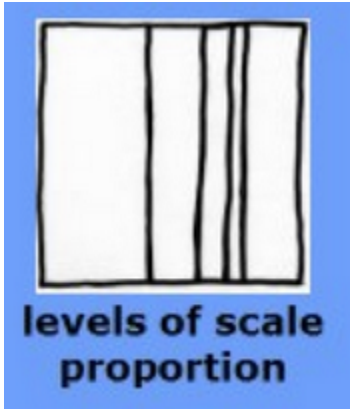
Image credit: Helmut Leitner

Example - Levels of Scale

- Objects with a high degree of life tend to contain a beautiful range of scales within them
- These exist at a series of well-marked intervals and have clearly recognizable jumps between them
- The jumps between different levels of scale should not be too great or too small



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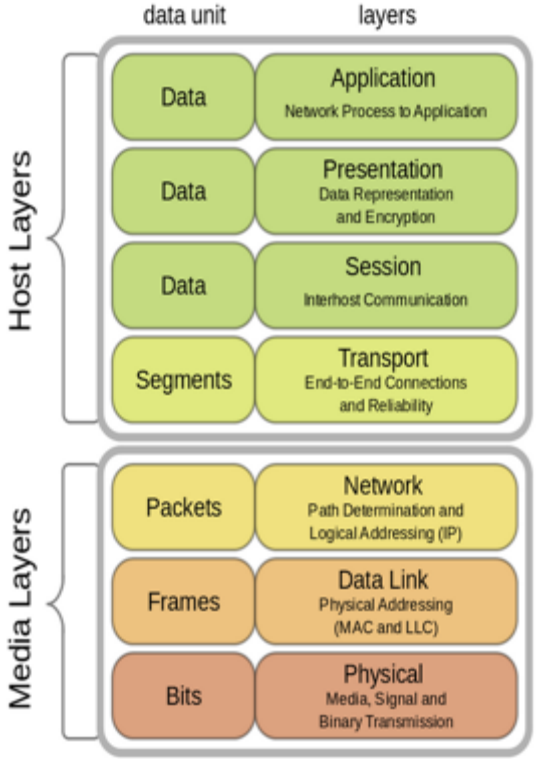
System Architecture - Levels of Scale

- Good system architectures make effective use of multiple levels of scale
- Example – Open System Interconnection (OSI) model



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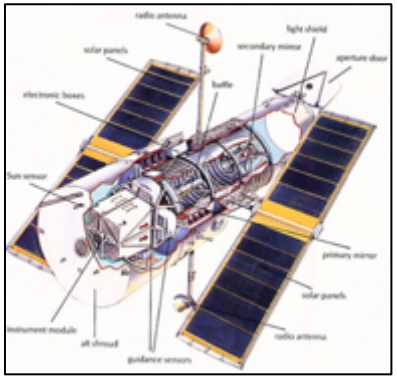
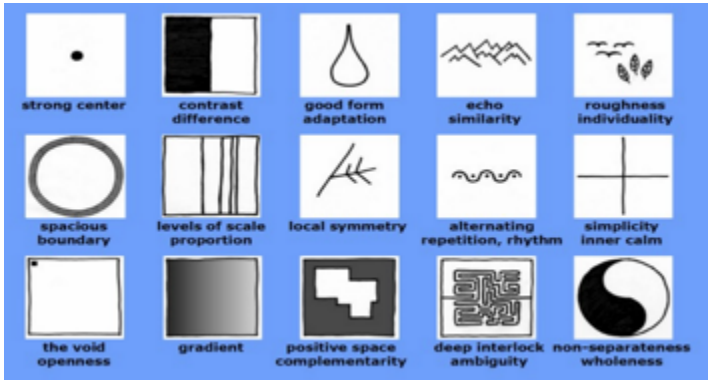
Beauty in Architecture

- Ideas not only applicable to system architecture
- Also, model-based systems engineering (MBSE)



Hubble Space Telescope System Architecture



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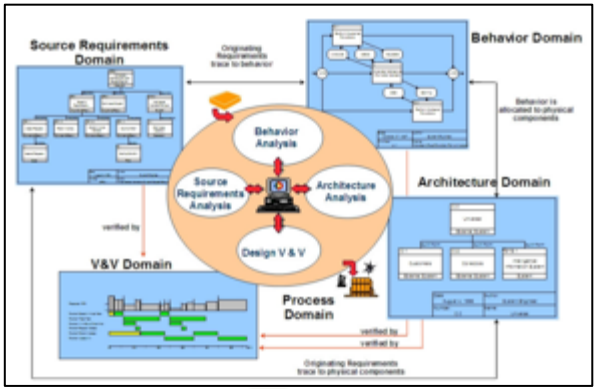


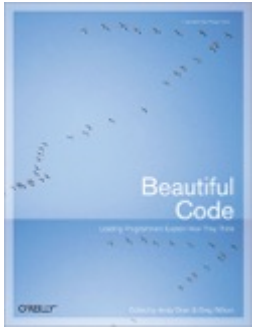
MBSE Domains and Diagrams

Hubble image credit: NASA / Public domain
MBSE image credit: NASA / Public domain

Beauty in Software

- O'Reilly Media
- Series of books on beautiful software

Beautiful Code (2007)
Beautiful Data (2009)
Beautiful Architecture (2009)
Beautiful Visualization (2009)
Beautiful Testing (2009)



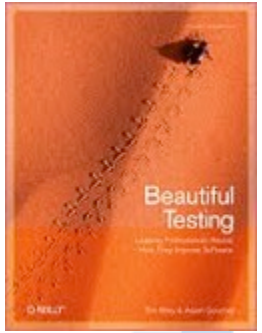
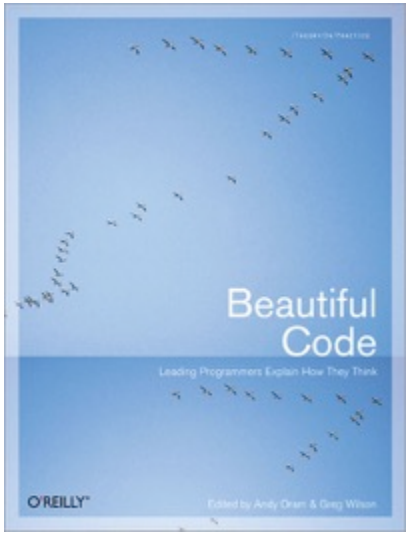


Image credits: O'Reilly Media

Beauty in Software

- Brevity
  - Beautiful code is short
  - Lengthy, complicated code is ugly
- Clarity
  - Beautiful code is simple and easy to understand
  - Complex, hard to understand code is ugly
- Balance between familiar and new
  - Beauty – novel, fresh, unique, insightful
  - Too exotic – hard to understand
  - Too familiar - boring



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Beauty in Requirements

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- Brevity
  - Omit needless words in requirements
  - Omit needless requirements
  - Help with knowing when to stop
    (no stopping rules for requirements work)
- Clarity
  - Use the customer's language
  - Avoid obscure terms and technical jargon
- Balance between familiar and new
  - Consider new ways to capture requirements

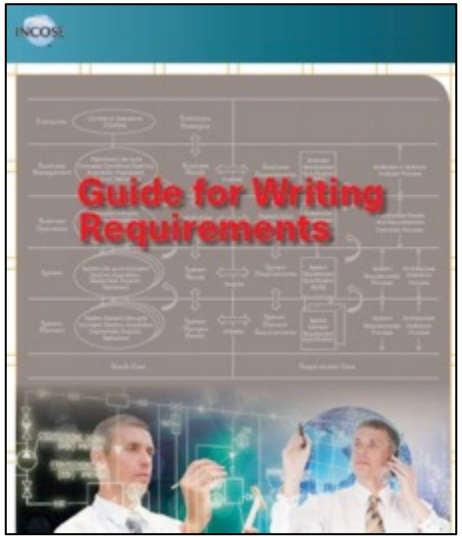


Image credit: INCOSE

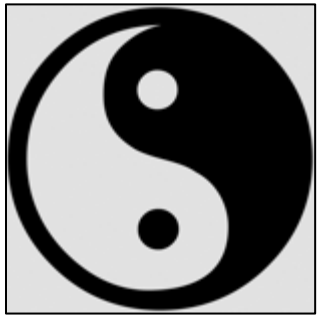
Beauty in Testing (1 of 2)

- Beautiful testing is
  - Effective – satisfies stakeholder objectives and expectations
  - Efficient – satisfies objectives while maximizing value
  - Elegant – achieves effectiveness and efficiency in a graceful, well-executed way
- Beautiful testing
  - Manages complexity well
  - Exhibits proportion and balance

Image credit: O'Reilly Media

Beauty in Testing (2 of 2)

- Symmetries exist in beautiful testing
  - Testing and writing
  - Testing knowledge and engineering knowledge
  - Low-level testing and high-level testing



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Beauty and the V Model

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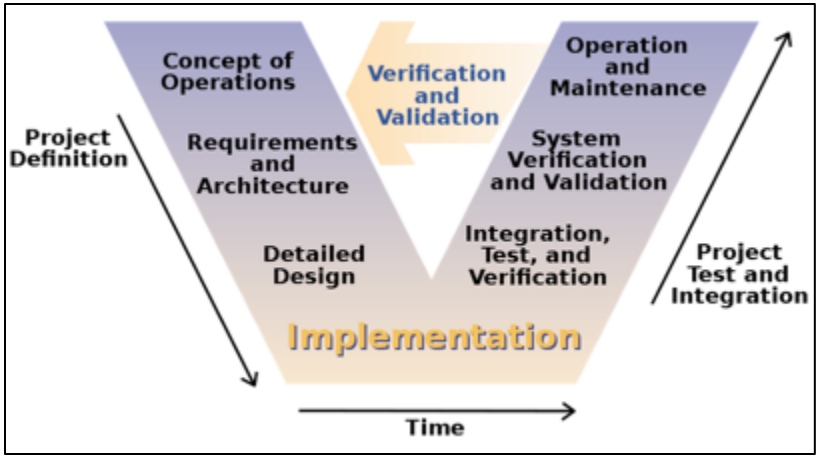
- The V model is a model of beauty
- Follows “nature’s artistic style”
- Symmetry and economy



V Model

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Summary

- Beauty is a useful guiding principle in SE
  - Symmetry - a love of harmony, balance, and proportion
  - Economy – producing an abundance of effects from very limited means
- Beauty can help guide SE activities
  - Make our work products easier to use
- Use ideas about beauty developed in the architecture and software domains

Other Ideas About Beauty

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- Beauty can be a sign of insight
  - "Art is technology plus insight" – Alva Noe
  - A quest for beauty can lead to deeper insights
- Beautiful solutions stand the test of time
  - Software example – CERN mathematical library is a good example of beautiful code
  - Written over 30 years ago, still in widespread use
  - If beautiful solutions are enduring, is beauty free?

Beauty as the Ultimate Goal

- At INCOSE IS 2015, some discussion about the ultimate goal of systems engineering
  - Manage complexity
  - Manage risk
  - Add value
- Maybe beauty is the ultimate goal
  - SE enables the development of beautiful systems (product)
  - SE seeks to accomplish this in a beautiful way (process)
  - Meet customer requirements, with efficiency and elegance

Thank You

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