The challenge of Quantum Technologies

Professor Michael Henshaw

Acknowledging Drs Mark Everitt, Vince Dwyer, and Jack Lemon, Kieren Bjergstrom and Susanna Jones

Professor Michael Henshaw

- Group Leader: Engineering Systems of Systems
- Director: MSc. Systems Engineering
- Lead: LU Secure & Resilient Societies Research Challenge
- Member: Quantum Systems Engineering Research Group
- Education
  - BSc. (Hons) Applied Physics, Hull
  - PhD. Applied Physics, Hull
  - MBA – Lincoln and Humberside
- Career
  - Research Associate, Physics, York 1987-1989
  - British Aerospace (later BAE Systems) 1989-2006
  - Professor of Systems Engineering, Loughborough, 2006 -

Loughborough University

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Quantum Systems Engineering Research Group

Research > Quantum Systems Engineering

Growing Awareness and Capacity in Quantum Systems Engineering

QSERG hosts a meeting to discuss the roles and importance of a quantum mechanical approach to systems engineering, primarily in order to transition state of the art laboratory science into deployable real-world technologies.

See *News* for more details

Why should Systems Engineers be concerned about Quantum Technologies?

Why should scientists pay attention to Systems Engineering?

Why should Systems Engineers be concerned about Quantum Technologies?

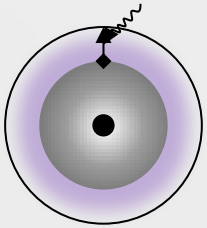
- 1st quantum revolution
  - 20th Century – quantum mechanics mathematics explained operation of devices (transistor, laser, etc.)
- 2nd quantum revolution
  - 21st Century – manipulation of quantum states:
  - Superposition
  - Entanglement
  - tunnelling

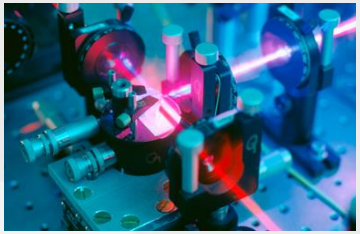
http://www.crystalinks.com/SchrodingersCat.html

Applications

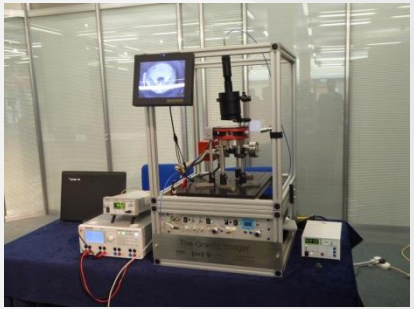
- Quantum clocks
  - Current atomic clocks ~2 X 10^{-16} s to Quantum clocks ~10^{-18} s
  - Application: space navigation, communications, and quantum cryptography
- – Quantum communication
  - Quantum Key Distribution (QKD)
- – Quantum computing
  - Offer 10^{8} X speed of conventional one core PC
  - Applications: Cryptography; faster than real time analysis of complex scenes; Quantum simulation!

- Quantum sensors
  - ▪ Gravimeters
    - ▪ Sensing through walls; Detection of materials and voids; GPS-free navigation; Scene imaging
  - – Rotation
    - Spacecraft guidance; Inertial navigation; Image stabilisation
  - – Enhanced imaging
    - LIDAR (improved resolution); Ghost imaging; Stealth imaging
  - – Quantum dots
    - Improved colour and resolution of screens
  - – Magnetic, Electric, EM sensors
    - Measurement of fields; Forensics – characterising nearby circuits; Detect objects through walls; Underwater sensing





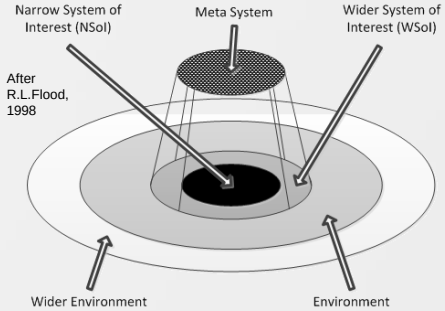
From: Austrian Inst. Technology



Gravimeter built by Birmingham University, image M Henshaw

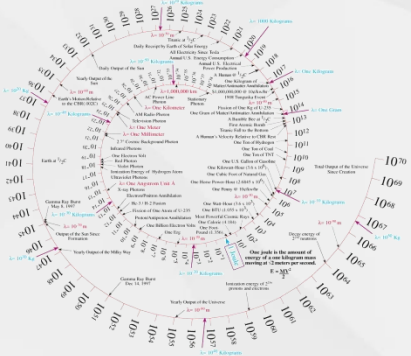
Technical Challenges for Systems Engineering

System of Interest



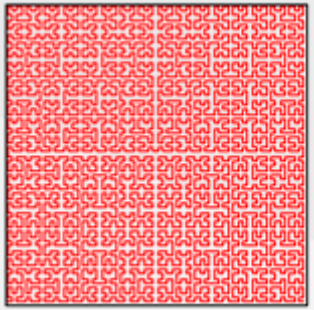
- Enabling systems may be strongly coupled (e.g. laser cooling of trapped atoms)
- Entangled entities – massive distances (ambiguity)
- Environment dependencies

Scale implications



- Macro-scale engineering combined with phenomena at relative scale 10^{-8}-10^{-16}
- Batch variability of nanomaterials
- Complexity of interfaces

Models



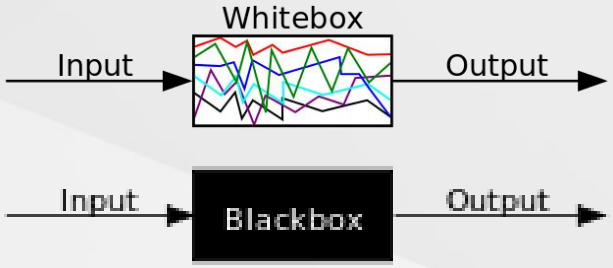
- Physically realistic models to complex for current computers
- Science and engineering models have different philosophical bases
- Models not validated for design

Work needed – based on ISO15288

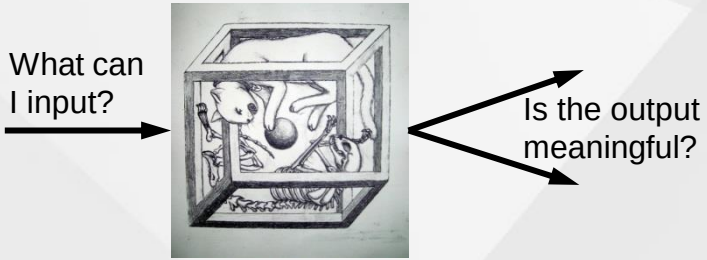
- Stakeholder needs/requirements definition (6.4.2)
  - Acceptance criteria (QT-specific)
- System requirements definition (6.4.3)
  - Lack of models to establish relationships between technical requirements
- Architecture definition (6.4.4)
  - Representation of new entities; SOI
- Design definition (6.4.5)
  - Lack of models for trade space analysis
- System analysis (6.4.6)
  - Partitioning of design – need for specialist QM knowledge
- Implementation (6.4.7)
  - Principles for reliability are unknown
- Integration (6.4.8)
  - Integration strategies must accommodate quantum effects to maintain robustness
- **Verification (6.4.9)**
  - **! (see next slide)**
- Validation (6.4.11)
  - Depend of well-defined stakeholder requirements, difficult for early adopters
- Maintenance (6.4.13)
  - Suitable monitoring strategies; QM knowledge for some devices
- Disposal (6.4.14)
  - How much rubidium is there? Need for recovery

Verification

- Cannot measure intermediate states
- Too many possible states to examine them all
- Complex, non-deterministic systems



Cat Box Testing



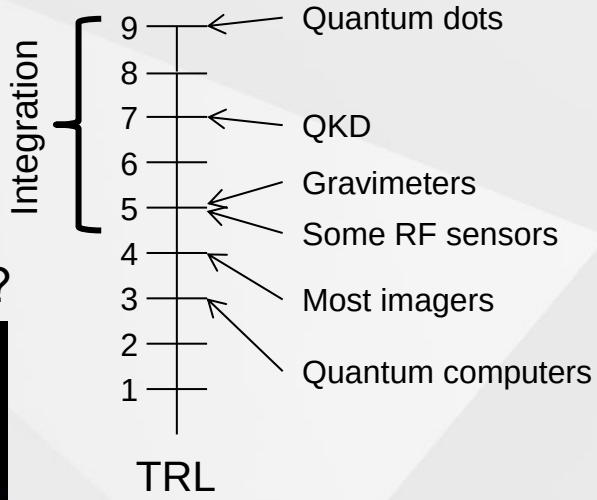
Why should scientists pay attention to Systems Engineering?

Phys.org; Quantum mechanic frequency filter for atomic clocks March 9, 2015

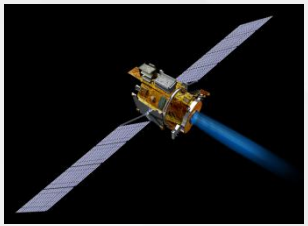
https://en.wikipedia.org/wiki/USS_Iowa_(BB-61)

What customers want

- Practical devices
  - Room temperature operation
  - Robustness
  - Size and weight
  - Scalability



Does the customer care if it's quantum?



QSERG training scientists

- Delivered “systems-lite”
  - to NQITs (Oxford Hub)
  - 30 Dstl Quantum Physics PhD students
  - *“I wish I had known about systems engineering when I started my PhD”*

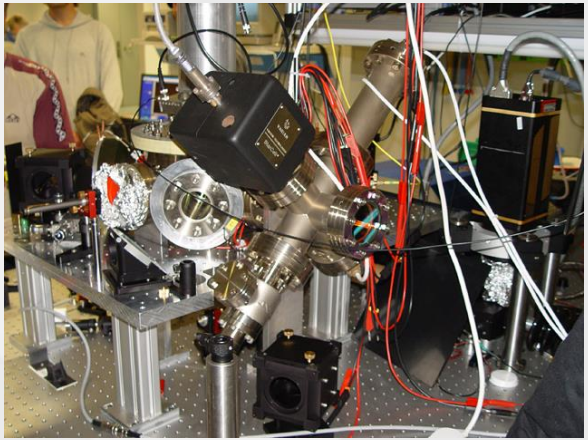
IEEE SYSTEMS JOURNAL

Transformational Effects of Applying Systems Engineering in Laboratory Scientific Research

Kieran N. Bjergstrom, William G. B. Huish, Michael J. de C. Henshaw, *Member, IEEE*, Vincent M. Dwyer, and Mark J. Everitt

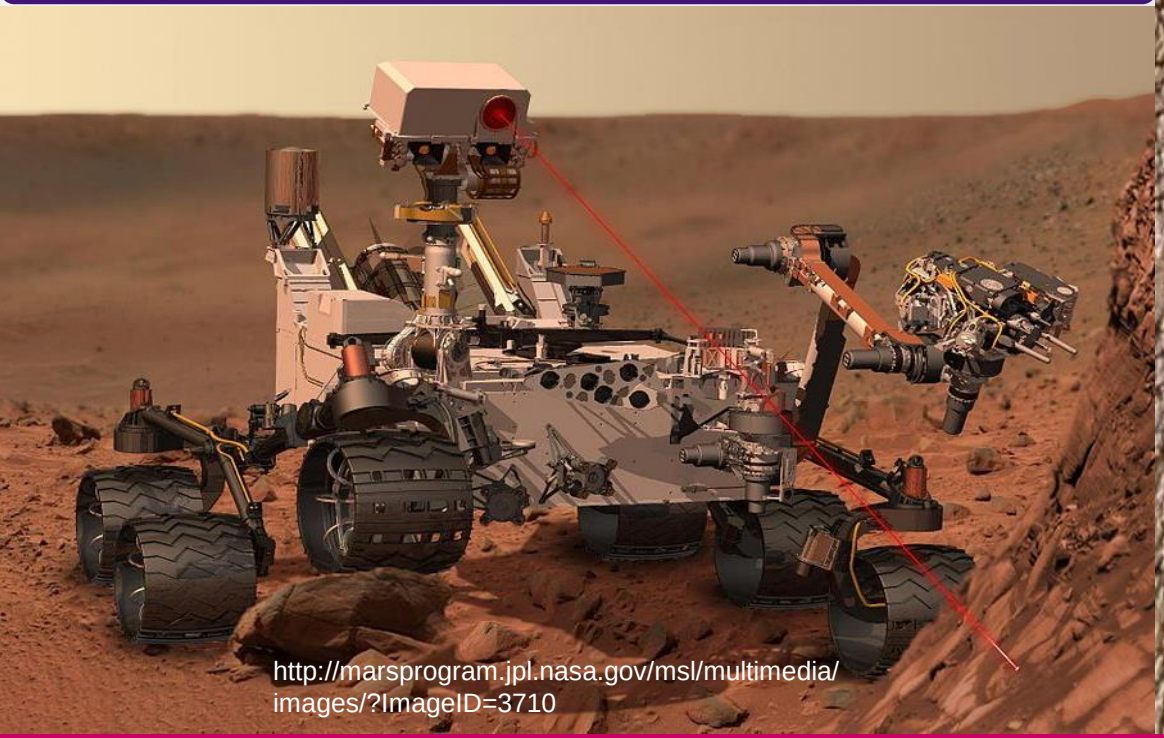
QSE Summer School Curriculum

- CONOPS
- Requirements using Systemic Textual Analysis
- Functional requirements analysis
- Functional Means Analysis
- Brainstorming and negative brainstorming
- Functional Failure Modes Effects Analysis
- Quality Function Deployment
- Verification and Validation
- Life-cycle analysis



Ion trap

Dear Scientist: what is the similarity between a Mars rover and a dead rat?



http://marsprogram.jpl.nasa.gov/msl/multimedia/images/?ImageID=3710

Conclusion

- Realisation of Quantum Technologies needs Systems Engineering, but
- Systems Engineering must be developed for the needs of Quantum Technologies
- Scientists make great systems engineers, if only they ever get to hear about it

Bjergstrom, K.N., Huish, W.G.B., Henshaw, M.J.deC., Dwyer, V.M., and Everitt, M.J., “The Transformational Effects of Applying Systems Engineering in Laboratory Scientific Research”, to appear in Ieee Systems Jour. 2018

Henshaw, M.J.deC., Everitt, M.J., Dwyer, V.M., Lemon, J., Bjergstrom, K.N., and Jones, S.C., “The Challenges of Quantum Technologies to Systems Engineering”, submitted.

More information

- QSE Research Group
  - http://www.lboro.ac.uk/research/quantum-systems/
- Prof. Michael Henshaw
  - http://www.lboro.ac.uk/departments/meme/staff/michael-henshaw/
- Secure and Resilient Societies Research Challenge
  - http://www.lboro.ac.uk/research/excellence/challenges/secure-resilient/