ICRAR

International Centre for Radio Astronomy Research

Systems Engineering in Radio Astronomy

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Outline

- Systems Engineering and problem solving
- (Very) basic Systems Engineering
- Useful heuristics
- Radio astronomy context
- The SKA

The human condition – problems, problems

- Curiousity and inventiveness are innate in humans
  - And other species we're not considering today
- The state of dis-contentedness is common
  - Results in the formulation of goals
- Getting from a present state to a goal is rarely automatic
  - Problem solving is an innate ability in humans
- We grade problems
  - Trivial, easy, hard, wicked, ...
- What makes a problem hard?
  - Lack of clarity about the situation or context
  - Multiple goals
  - Complexity (large number of items, inter-relations and decisions)
  - Dynamics (time constraints, changing parameter sensitivity, unpredictability, ...)
  - .....
- Of itself, scale may not make a problem 'hard'

Problem solving

- Definition: the steps to solve the problems standing between you and your goal
- Many discipline-dependent formalisms exist for problem statement
- Many problem solving formalisms exist across a variety of disciplines
- A common broadly applicable "cycle" is
  - Recognize problem; define problem; develop a strategy to fix problem; organize knowledge; figure out resources; implement solution and monitor progress; evaluate solution
- What techniques do we use in problem solving strategies?
  - Abstraction; analogy; brainstorming; divide and conquer; lateral thinking; morphological analysis; research (has someone else solved it?); trial and error, transformation/reduction, ...
- *Systems Engineering* is one way humans solve some complex problems

Systems Engineering (SE)

- Systems Engineering is a formal process for the development of complex systems driven by a set of established requirements (Tom Weisgerber)

- Many historical projects – back to Mesopotamia, Egypt, Greece – employed what would now be called SE practices
  - Aquaducts, irrigation systems, highways, ...

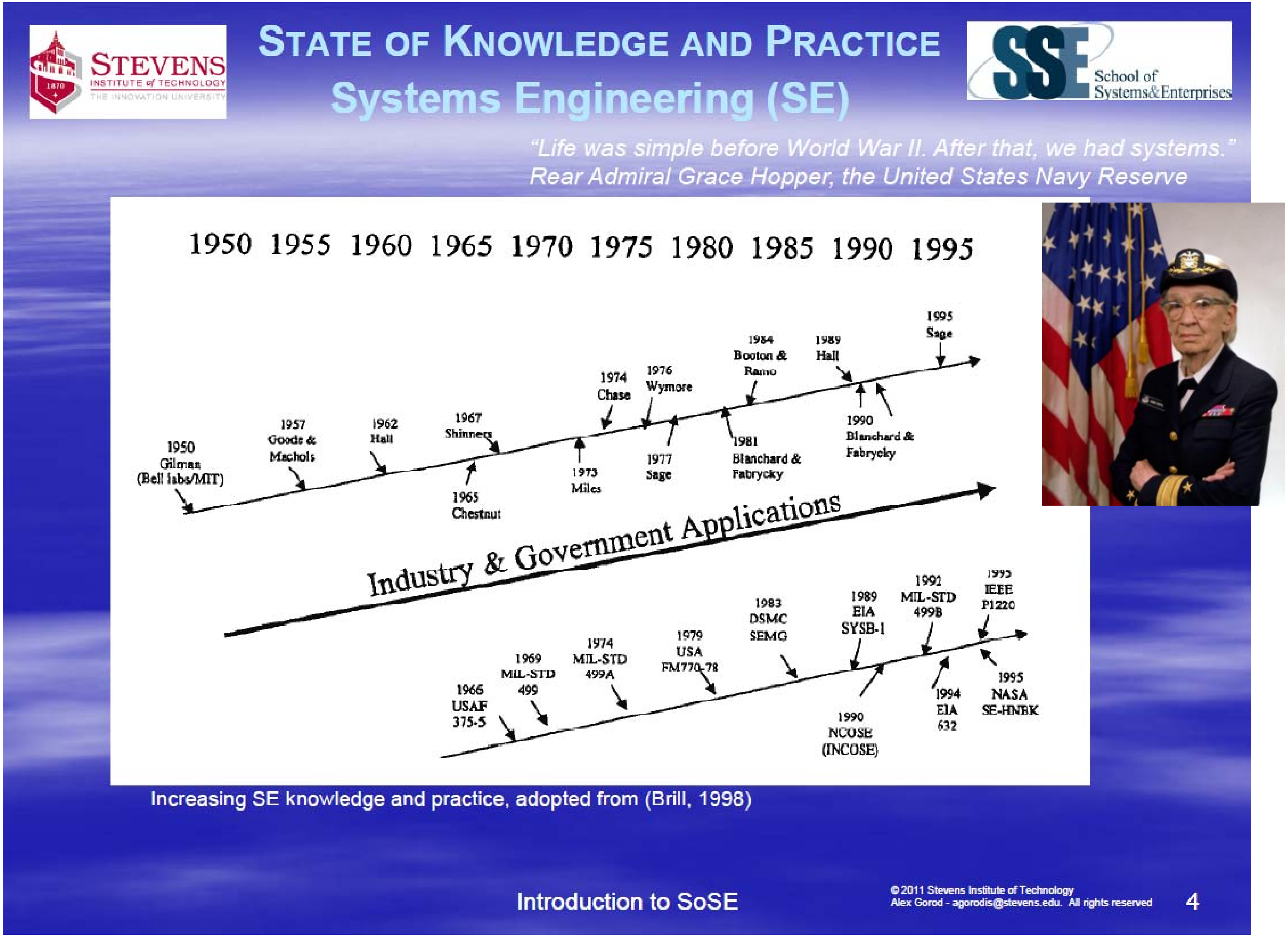
- SE as we know it began to emerge in the late1930s and 1940s
  - But Bell Telephone Labs used an evolving version of SE from early 1900s

- Major SE driver was weapons system development, e.g.
  - British multi-disciplined team for Air Defence analysis (1937)
  - Bell Labs (Nike, 1939-45)
  - MIT (SAGE, 1951-80)

- US DoD MIL-STD-499 (released 1969) was a major milestone

- SE diffused outwards from military, NASA, defence and aerospace contractors to wider engineering world (e.g. IEEE and European engineering counterparts)

- SE flame now guarded by INCOSE (amongst others)
  - International Council on SE

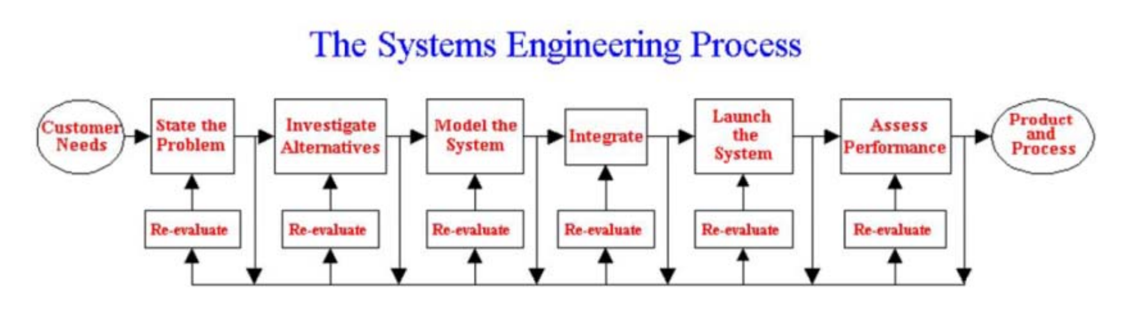


After Gorod, 2011

Elements of Systems Engineering

- Systems Engineers like to stress the need for:
  - Interdisciplinary process
  - Understanding the whole problem
  - Testing the total system before delivering it
  - Life cycle considerations (including operations, de-commissioning, disposal, ...)
  - Documentation

- Canonical process follows the SIMILAR rule:
  - **S**tate the problem
  - **I**nvestigate the alternatives
  - **M**odel the system
  - **I**ntegrate
  - **L**aunch the system
  - **A**ssess performance
  - **R**e-evaluate



- "**A bit of marketing, a bit of management, a whole lot of engineering, and risk management**"

The <u>real</u> laws of SE

- **Everything interacts with everything else**
  - Decomposition
- **Everything goes somewhere**
  - Interfaces
- **There is no such thing as a free lunch**
  - Trade studies
- Selected home truths
  - *Never confuse change with progress*
  - *Never be afraid to start over*
  - *Never be above plagiarism*
  - *A thing not worth doing is not worth doing well*
  - *There is no shelf*
  - *Nothing is impossible to the man who doesn't have to do it*
  - *One test is worth a thousand expert opinions*
  - *Never have more than 10 blocks in your block diagram*
  - *After all is said and done, a lot is said and very little is done*
  - *Deny everything, admit nothing, demand proof, and reject the proof*

After D. F. McClinton

Systems Engineers

- During product development, Systems Engineers frame solutions:
  - Develop the architecture of the solution
    - Sub-systems, internal and external interfaces
    - Detailed operational concept
    - Project “building code” - standards and conventions
  - Validate the design (modelling, simulation, prototyping)
  - Specify sub-systems
  - Optimize design and balance life-cycle issues
    - Cost, deployment, reliability, maintainability, supportability, human interfaces, ...

- Knowing the process does not make one a Systems Engineer
- SE processes *increase the odds of success but do not replace sound engineering judgements*
- Reviews and documentation are important but *good SE does not encourage bureaucracy*
- Inter-disciplinary teamwork is essential
- Good Systems Engineers have *strong domain knowledge*

Systems Engineering does work !

- Many successful, ambitious, public and private projects are the products of good Systems Engineering

- Having **a process** is much more important than having **any particular tool**
- SE adds to project costs
  - But lack of SE in complex projects is normally a disaster
  - "No time to do it right, always time to do it twice"

- SE investment can, and should be, commensurate with the project scale

Classic observations on SE
- Robert A. Frosch (USN, NASA)

- Prescriptive technique no substitute for talent and capability
  - The concerto analogy
- Blaming deficiencies in management systems (SE) for problems from real unknowns or human deficiencies is foolish
  - "*The glass is falling hour by hour, the glass will fall for ever. But if you break the bloody glass, you won't hold up the weather*" (Louis MacNeice).
- Path to success
  - "... *competent person and assistants..who understand the problem, not the specifications of the problem, not the written scenario but...what is in the minds of those who have..the requirement*"
- We are using our best people to fill in documentation...most of the time no one is running the store
- SE is an art, not a science: engineers should ask whether a final product is good, harmonious, elegant
  - Bring art and excitement back to engineering
  - No techniques or tools will help people who lack talent, competence and enthusiasm

Radio astronomy projects

- Big projects of 1970s and 80s relied on “hero” models and small senior teams
  - Effective communication, clear goals
    - Many aspects of contemporary SE implemented de facto
  - Intuitive control of complexity, sensitivity analysis and trade-offs
  - Fairly “lite” project management relative to (e.g.) military projects of the day
  - Generally good outcomes in cost + performance terms
    - Discovery instruments? Another discussion !
  - Technology development was (rightly) seen as the key enabler

What about the benefits of OVER-DESIGN ?

- A proud (cost-constrained) achievement of the **1960s**
- Example that extreme optimization against specifications-of-the -day restricts future flexibility
- This “un-optimized” project may be our single most successful radio astronomy discovery instrument

Caption: CSIRO’s Parkes radio telescope. Credit: David McClenaghan, CSIRO

Current projects: how are we doing ?

- **ALMA**: grief and pain, but on-track to be a highly productive telescope
- **LOFAR, MWA**: grief and pain, but outstanding science emerging
- **ASKAP**: grief and pain, results to come
- **MeerKAT**: not far enough along for grief and pain

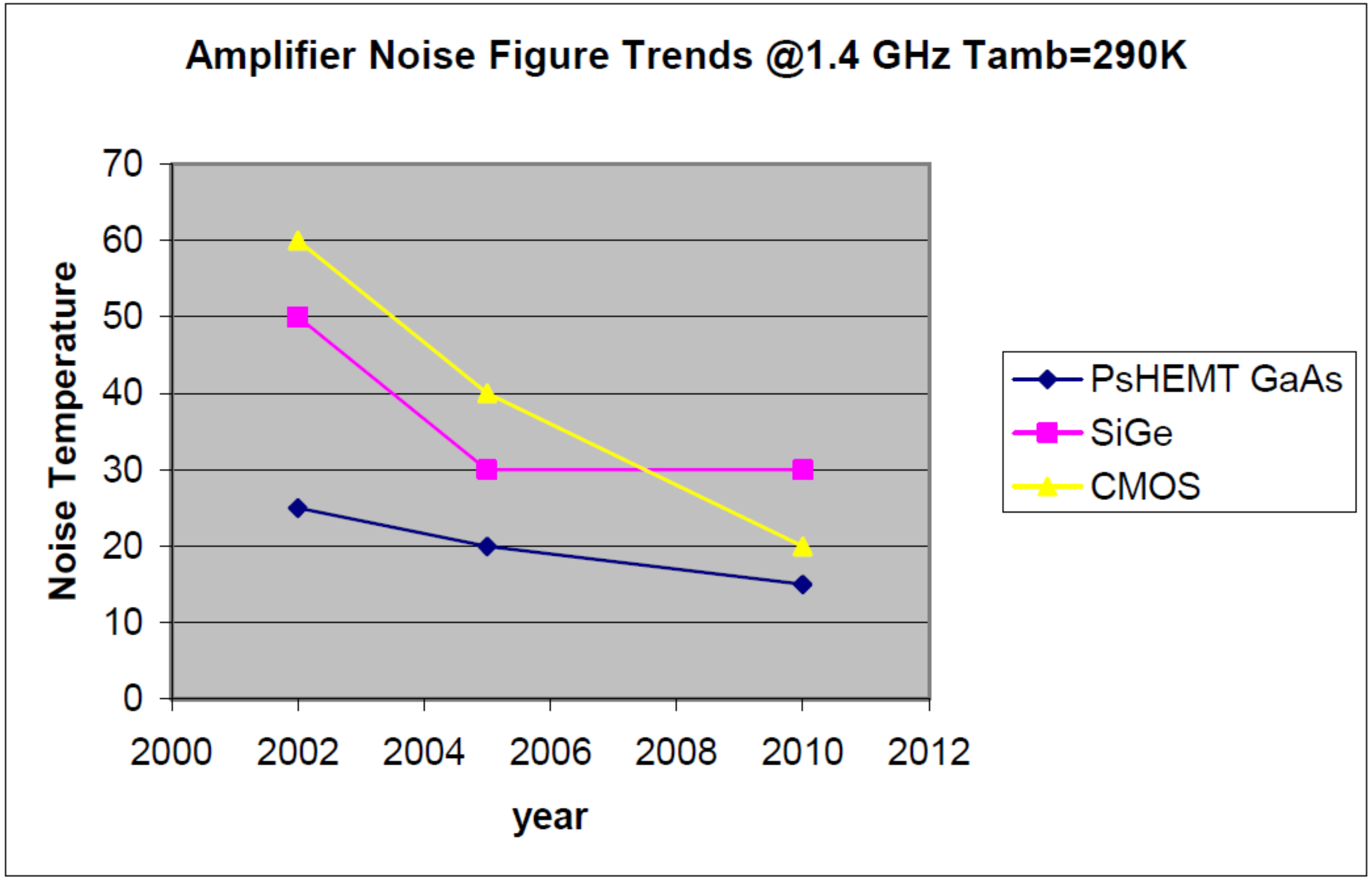
- Specification setting, realistic costing and expectation management remain big issues
- Experiments with Systems Engineering have produced variable results
  - Better requirements matching and specification traceability
  - Struggle with "right-sizing" SE across project phases
  - Struggle integrating productive early science (LOFAR excepted?): did SE get in the way?
- More stakeholders, much more accountability than earlier projects – good or bad?

Systems Engineering for SKA

- SKA is large, complex and geographically dispersed
  - Definitely need SE
- Key enabling technologies and/or technology cost optimizations remain under development
  - Hunt for, and belief in, centralized SE clouded this truth for some time
  - Process no substitute for inspiration
- Elements of SE decomposition are generally sensible and workable
  - But are essentially the same as those in long-standing modular view of the SKA

Swinburne Astronomy Productions/ICRAR/U.Cambridge/ASTRON

AvA: focus on enabling technologies



c. 2001-2

SE for SKA (continued)

- Failure to integrate technology development platforms (pathfinders) and central SE design effort
  - But reality has taken us back to the “extended pathfinder” model, as was inevitable
- SE has not addressed site-related or infrastructure issues well
  - Despite lessons from astronomy and other projects that these are the main culprits in project failures
- There is cause for optimism
  - Site and technology decisions mean we have a strong practical interest in getting on with the job, and doing it right
  - Consortia and regional teams will be the main SE practitioners (strong links with reality)
  - There are real system optimizations to come from the SKAO, provided simultaneous SE and domain expertise can be found
  - The pace of SKA engineering can and should be accelerated; pre-con is a major engineering project

Project pace is important !