Advanced Technologies to Enable Simulation of Life-Cycle Sustainment of Weapon Systems

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for his Co-authors

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The authors of this paper concur with ONR Public Release as indicated in the following correspondence:
Email from Daniel P. Burns to Lynn Petersen, Subj: 43-1984-16 - Life-Cycle Sustainment Paper, dtd 29 Aug 2016
Email from Ke-Thai Yao to Jeffrey Smith, Subj: Full Release from USC for CAPT Petersen's Paper, dtd 29 Aug 2016
Email from Dan M. Davis to Jeffrey Smith, Subj: DDavis and Full Release from USC for CAPT Petersen's Paper, dtd 29 Aug 2016

Major and Minor Theses

System engineering (SE) of life-cycle sustainment of weapons systems and simulation of those systems are interconnected and co-dependent.

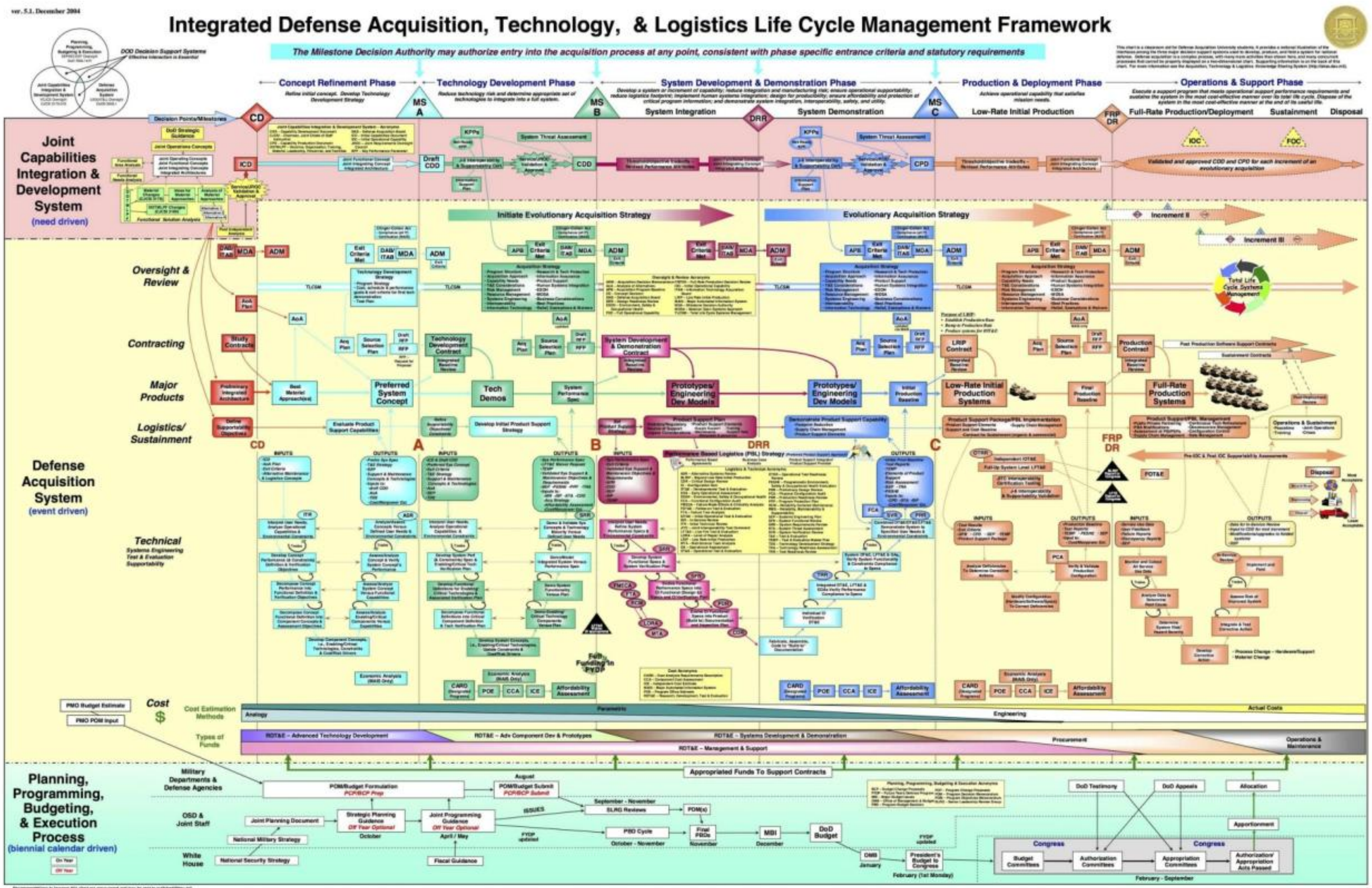
The two communities should collaborate in providing their insights to each other and using the other's capabilities to enhance their own

New technologies will enable both and facilitate increased collaborative efficiencies.

System Engineering Life-Cycle Sustainment for the DoD

- Weapon Systems are increasingly expensive, vital and fragile
- Planning is required for sustaining these systems
- Math models used: Markov, hidden Markov and martingale
- Effective and validated M&S can significantly reduce the cost of the "Design-Build-Test Repeat until right" scenarios
- SE and Modeling and Simulation (M&S) should collaborate:
  - SE should make use of large-scale simulations to improve their system design and sustainment planning
  - Simulators should integrate sustainment functions and impacts into their simulations

Life-Cycle Framework



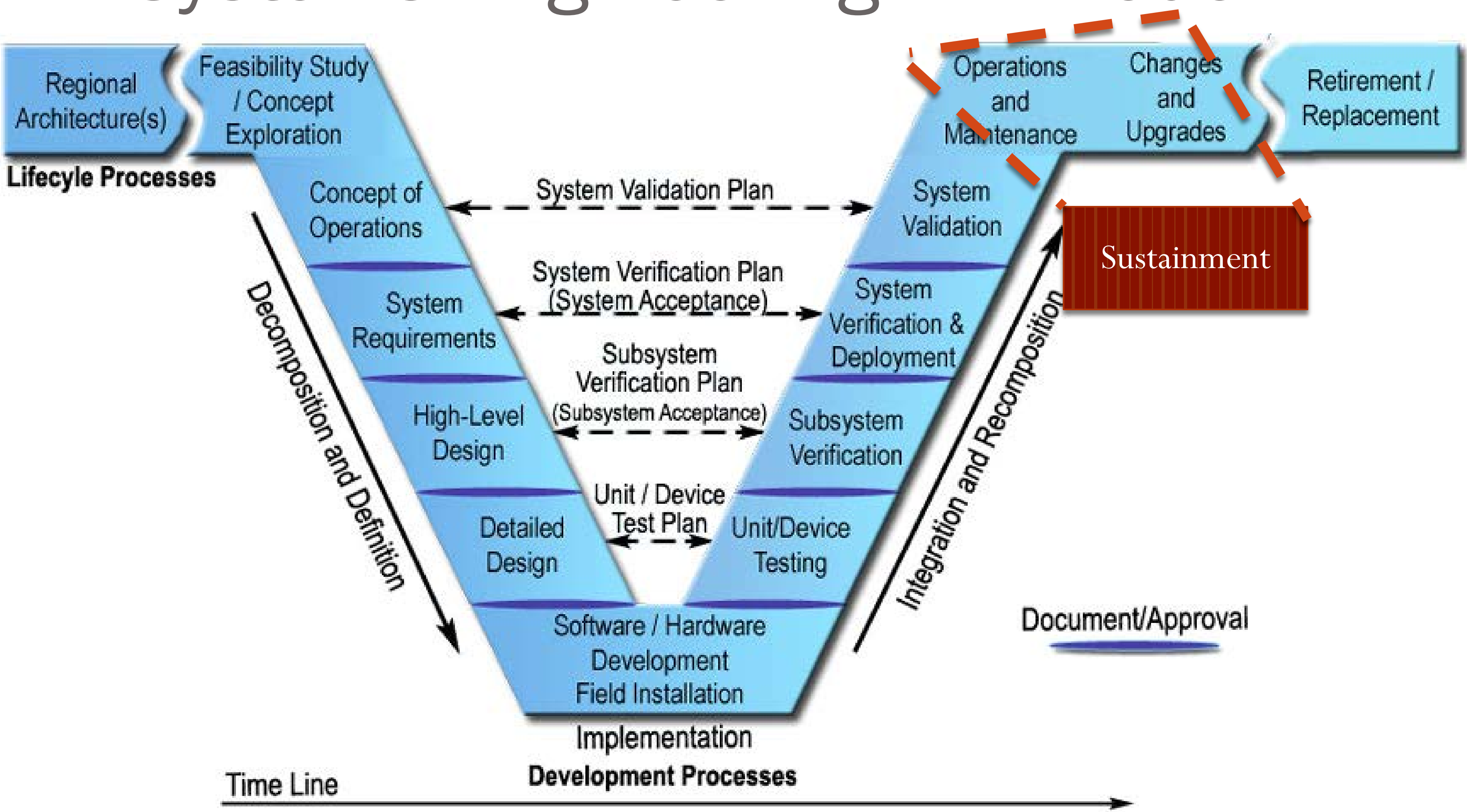
System Engineering and Simulation

- It is an accepted rule of thumb in the analysis community that more than four parameters require formalization
- Some parameterization of the problem becomes necessary
- Various forms of linear algebra analysis were done by hand
- Advent of computer simulation gave vast improvement
- Reconsider the flow chart on the previous slide and contemplate its need for machine assistance in analysis

Simulation and System Engineering

- Battlefield simulation has been accused of being too idealized
- Live “blue forces” don’t always follow doctrine
- Asymmetric “Red forces” don’t always act as expected,
- Failing to incorporate all of the parameters and sustainment functions identified by SE’s introduces invalid tendencies
- Simulators have the computer power to properly implement the insights from the SE community

Systems Engineering "V" Model



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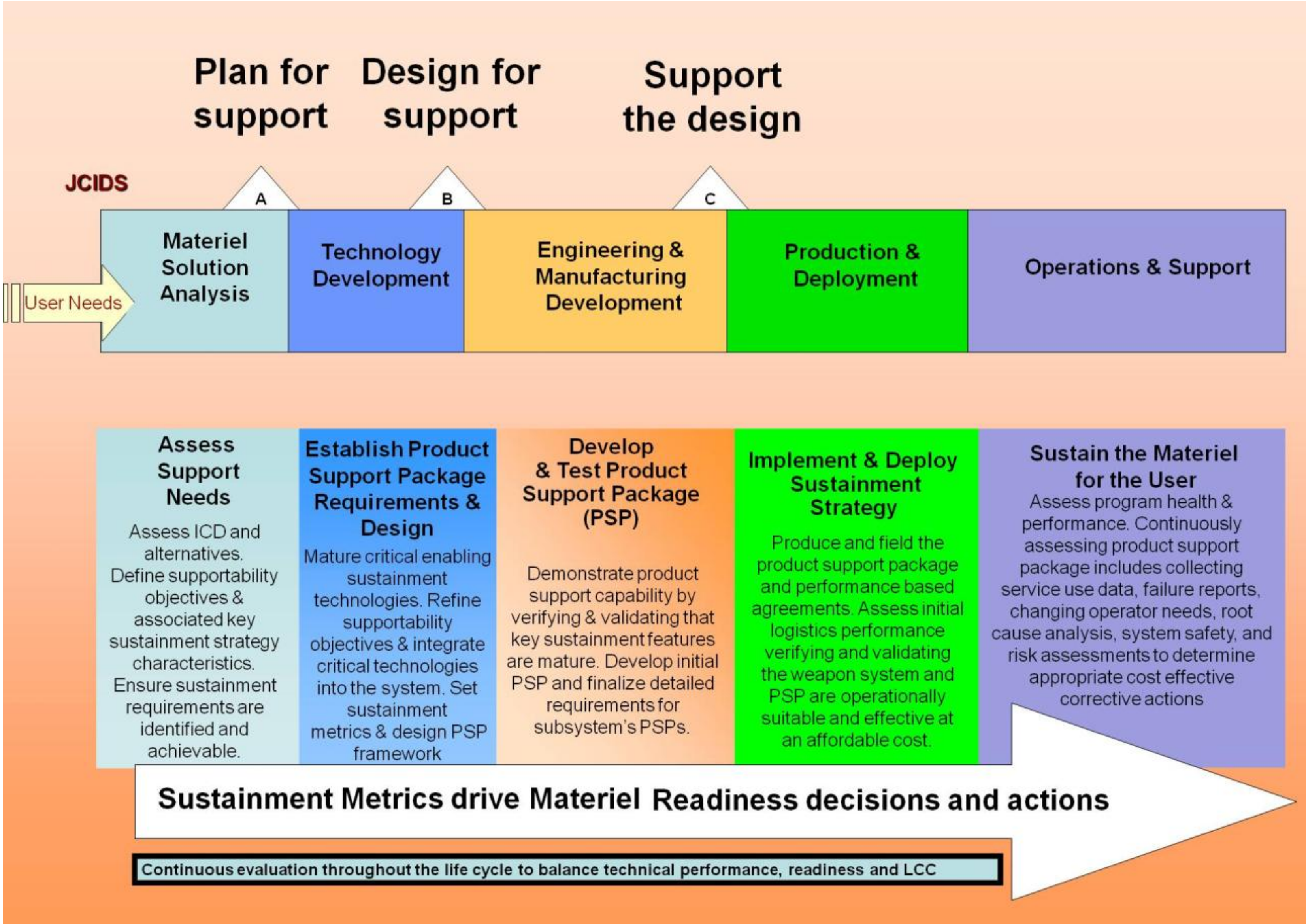
Source: http://ops.fhwa.dot.gov/publications/seitsguide/section3.htm

Life-Cycle Sustainment Analyses

- Degradation of systems and cost of operations often left out of many battlefield simulations
- External factors have exacerbated the constraints on battlefield commanders
- SE's find that two thirds of a system's cost are in operations and maintenance: these could be simulated
- Inversely, proper M&S will help the SE community plan better, *ergo* reduce total expenditures
- SEs' *forte* is risk identification and mitigation
- The staffing of maintenance personnel would be improved

Simulation Important at Every Stage



Markov, Hidden Markov & Martingale

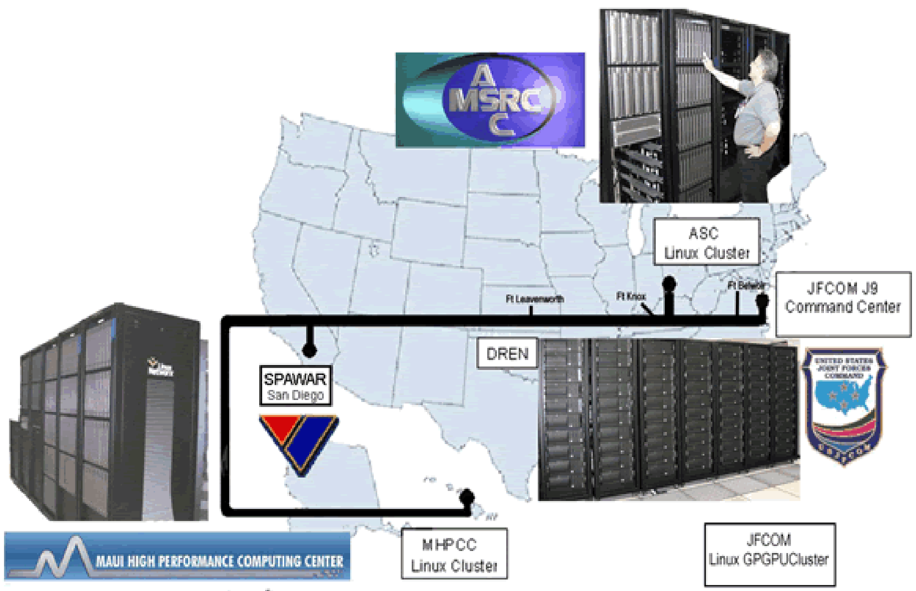
- Markov analyses posit the existence of a chain of events in which each even is independent of previous events
- A germane instance is the fall of an artillery round within the trajectory dispersion ellipse
- Hidden Markov posits that the chain of event has some observable result, but the state itself is not observable
- An instance of this might be the knowledge that some unobservable units never attack in the observable rain
- Martingale chains posit that the mean of all previous states eventually equals the current and future states
- The fall of all of the rounds within the trajectory ellipse

Markov and Martingale Analyses

- There are well-developed formulae and algorithms for all of the Markov and martingale processes (details in paper)
- Depending on the topic in issue, programming these functions into simulations should be straightforward
- Significant differences of opinion do exist about which live processes are best described by which process model

Enabling Technologies - Clusters

- Moving simulation from the war game table to today's simulations did require the advent of computers
- Advancing it simulation to global scales required large, dispersed and powerful computer clusters



JFCOM's Project Joint Experimentation on Scalable Parallel Processor s running JSAF transcontinentally

GPGPU Acceleration

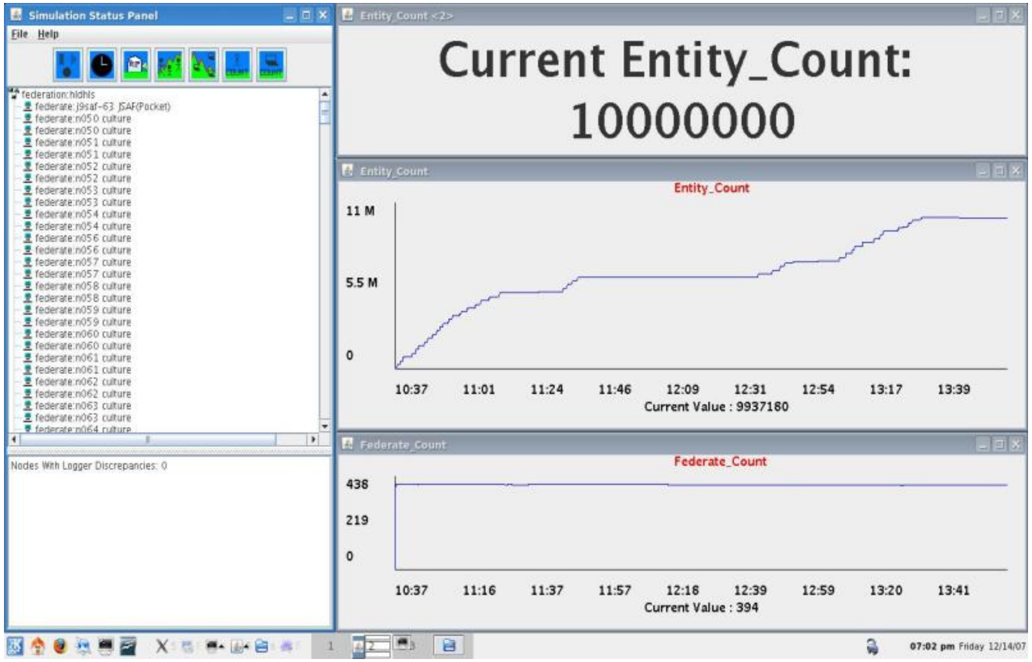
- Power and cost constraints were addressed by adding efficient General Purpose Graphics Processing Units to each node
- The DoD's High Performance Computing Modernization Office provided the machine which was installed in Norfolk

Joshua – JFCOM's Cluster
256 nodes, 1025 AMD Santa Rosa Cores, 256 NVIDIA 8800 GPUs, 18 GB RAM

The GPUs more than doubled the compute power

Performance Gains

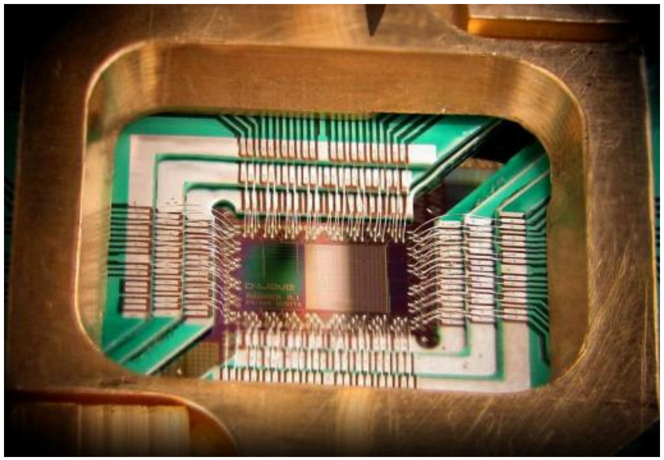
- GPGPU's provided enough power to radically extend the simulation using JSAF to model Baghdad
- Also modeled demographically correct populations and infrastructure along with red and blue forces
- A total of ten million entities were easily displayed with no suggestion that scalability was limited at all



Emerging Quantum Capability

- Richard Feynman of Caltech proposed the unfathomable power of a "Quantum Computer" in the 1980's
- Instead of a binary switch with a value of one or zero, the units would be a "cubit" with a quantum range of values.
- General purpose quantum computing is still the stuff of speculation and vociferous argument.
- D-Wave has delivered a few quantum annealers, one to USC
- Another is Google's and is in the San Francisco Bay Area
- They operate at a rather chilly 0.0015K (15 milikelvins)

USC's D-Wave Quantum Annealer



- D-Wave 2
- ~ 1,000 cubits
  (stable after cooling)
- Six way connectivity
- Marina del Rey California

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D-Wave Quantum Annealer

- Quantum Annealing (QA) is the analog of simulated annealing, *i.e.* a very effective optimization process
- Instead of optimizing by repeated iteration of binary parameters, QA can optimize by virtually limitless representations of parameters by the cubit's quantum state
- Like classic Christensen disruptive technologies, quantum annealing has its detractors and suffers from growing pains
- Most now agree that it is showing consistent and reliable quantum computing, but has not yet shown anticipated computational advantage over large digital clusters

Future for QA, Simulation and SE

- Expectation is that continued programming advances will see the exponential power growth anticipated
- Current machine has 2,200 cubits, with half turned off, so doubling power is immanent
- Six-way connectivity may limit number of parameters to be considered during optimization; there are plans to grow
- Both M&S and SE have repeated and large optimization functions that are inherent in their activities.
- QA should provide a new tool in overcoming these hurdles

Conclusions

- SE and M&S could both benefit by closer collaborations
- Just the act of parameterizing the functions often is insightful
- Coding challenges in implementing known M&S and SE function in the Quantum Annealer should be possible
- The capabilities of the D-Wave and subsequent quantum computing devices remains to be seen
- Current progress in QA is expected to continue
- The costs of applying SE principles to simulation would be justified by the increase validity of the data

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