Cellular-Satellite, a Different Kind of Final Frontier

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Introduction

• Explore the notion of “cellularity” as a motif for the creation of complex systems
• Embraces and extends concepts of plug-and-play, modularity, reconfigurability
Unobtainium

• This talk is about unobtainium
• Everything at one point was unobtainium
• Process of discovery: frustration
  – Many of our most-prized innovations have emerged as responses to frustrations encountered in our research and experimentation efforts
  – Example: plug-and-play
Background-Prior Developments Influencing CellSat Concept

• Molecular electronics
• Advanced packaging / MEMS / miniaturization
• Molecular electronics
• Multifunctional structures
• Reconfigurable systems
• Molecular electronics
• Plug-and-play
Nature’s self-assembly

Before RNA-trigger

Spontaneous Assembly After Trigger
• What can we learn from nature about self-assembly?
Can we create a self-organizing spacecraft based on cellular elements?

Protosat

Macrosat
Why would we want to?

• Flexibility – The ability to repurpose systems flexibly in the field
• Robustness / resilience – The ability to recover from defects, faults, damage
• Speed in the construction of systems – nearly instant systems
Key ideas

• Cellularity / Atomicity
• Intelligent Configuration Management Framework
• Recursive Reconfigurability
• A new Moore’s Law
Cellularity / Atomicity

• The idea of “effective” indivisibility in objects of hardware, software, concepts

• Common examples
  – “actual” atoms (i.e., from periodic table)
  – linguistic atoms (letters, words, etc.)
  – logic (transistors, gates, etc.)

• More abstractly
  – Black boxes (as in encapsulated form of hardware and software)
  – Concept of “no user-serviceable parts” within (Vernor Vinge, Rainbow’s End)
AFRL’s “Guided Self-Assembly”

- Artificial cellular experiments conducted 2003-2005
- Cells employ DNA-like functionality
  - Structures “inherit” a genetic sequence
  - Each structural element “knows” the entire structure (hundreds to millions of elements)
Guided self-assembly
Guided self-assembly
Guided self-assembly
Modular Robots (Xerox PARC)

- Robots built as collection of identical hardware/software modules with actuators, sensors
- Capable of cooperative function and dynamic morphing
  - Locomotion
  - Reconstitution
Guided self-assembly – self repair
Guided self-assembly – self repair
Guided self-assembly – self reproduction
Cellular Architecture

- A simple “LEGO” universe
Brainy Cells?

- Cells contain ability to manage artificial DNA, understanding of own state, state of neighborhood
- Connections can be manual, automatic, locomotive
Rules

• Rules define connective relationships between cells

• Worst case rules have high Kolmogorov complexity

Cellular automata have simple rules
Nature has simple rules (simple virus 3k-5k symbols from 4-symbol alphabet)
(Recursive) Reconfigurability

- Definition: software-definable functionality
- Reduction of functions that personalize a cell (system) as a set of 0-1 decisions
Simple example of recursive reconfiguration – field programmable gate array (FPGA)
FPGA example - continued

Final “DNA”

01000001000010….1110…0110…0101
A (future?) generalized reconfigurable analog system
Augmenting Architecture of Cell for Reconfigurability
Augmented Cellular Architecture

- **Payload**
- **Config Mgt**
- Connection port

- **Electrical, thermal, etc**
- **Attachment**
- **Configuration only**
Example: Pixilated Antenna

(a) $\sigma = \sigma_0 = 0$
$\varepsilon = \varepsilon_0$

$\sigma = \sigma_1 = \text{inf}$

(b) (c)
Example Possible Cell types

- $\sigma$-cells, a family of cells relating to the exploitation of conductivity;
- L-cells, a family of the familiar lumped element electrical blocks from simple circuit theory (resistors, capacitors, transistors);
- $c$-cells, computation / storage elements (variations of those found in FPGAs);
- $k$-cells, programmable thermal elements;
- $\varepsilon$-cells, programmable permittivity;
- $E$-cells, pertaining to energy storage;
- $g$-cells, programmable mechanical attachment;
- $s$-cells, for sensing phenomenologies and converting them to electrical signals;
- $\mu$-cells, for programming permeability;
- $\eta$-cells, for photonic (light-routing) applications;
- $\alpha$-cells, for transduction / actuation (conversion of electrical signals to some other phenomenology, including locomotion);
Example Cellular wiring harness

(a) Switch Matrix
(b) Config Mgt

Shift input

Shift register (conveys bitstream to payload)
PnP Architecture

1. RXN X
2. RXN Y
3. RXN Z
4. Therm
5. Therm
6. Hub
7. Software Radio
8. Hub
9. Hub
10. C&DH
11. Simple Camera (w. hub)
Cellular Construction of Spacecraft
Summary

• Cellularity has been suggested as a powerful motif for future systems
• Discussed concepts and implications
• Not totally ready for prime time
  – Practical (useful?) demonstrations will be possible in limited domains with 3-5 years
• Limit argument is compelling – smart dust, instant systems