Evolving Critical Systems

Prof. Mike Hinchey
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Welcome to today’s ACM Learning Webinar, “Evolving Critical Systems” by Mike Hinchey. The presentation starts at the top of the hour and lasts 60 minutes. Slides will advance automatically throughout the event. You can resize the slide area as well as other windows by dragging the bottom right corner of the slide window, as well as move them around the screen. On the bottom panel you’ll find a number of widgets, including Twitter, Sharing, and Wikipedia apps.

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• Submit questions and comments via Twitter to @acmeducation – we’re reading them!

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66 Years Ago ...
EDSAC

- 650 instructions per second.
- 1024 17-bit words of memory in mercury ultrasonic delay lines.
- Paper tape input and teleprinter output at 6 2/3 characters per second.
- 3000 valves, 12 kW power consumption, occupied a room 5m by 4m.
- "Operating system" occupied 31 words of read-only memory.
- Early use to solve problems in meteorology, genetics and X-ray crystallography.
Difference Engine
Errata, detected in Taylor’s Logarithms. London: 4to, 1972 [sic]

...  

$Kk \cos$ine of $14.18.3 - 3398 - 3298$

**Nautical Almanac (1832)**

...  

In the list of ERRATA detected in Taylor’s *Logarithms*, for $\cos. 4 \ 18’ \ 3”$ read $\cos. 14 \ 18’2”$.

**Nautical Almanac (1833)**

ERRATUM of the ERRATUM of the ERRATA of TAYLOR’S *Logarithms*. For $\cos. 4 \ 18’3”$, *read* $14 \ 18’ \ 3”$.

**Nautical Almanac (1836)**
First Programmer

Augusta Ada King, Countess of Lovelace
Software Lags behind Hardware

![Graph showing the availability of telephone and computer systems from 1950 to 2000. The graph indicates that computer systems have a higher availability than telephone systems.](image-url)
Software vs. Hardware

• Pervasive yet non-obvious;

• Abstract as opposed to “concrete”;

• Perceived to be “easy to change”;

• Easy-to-change means often changed;

• Not visibly deteriorating.
Wear versus Deterioration

Graph showing the relationship between failure rate and time, with a note on increased failure rate due to side effects and a change in the actual curve compared to the idealized curve.
Major Software Failures

• Therac 25

• ARIANE 5

• Mars Polar Lander

• … and many many more!
The problem is Complexity.

*Bill Gates*
Size of Modern Applications

Source: Ebert & Jones, *Computer*, April 2009
Increasing Size

Source: Ebert & Jones, *Computer*, April 2009
Challenges for Software Engineering

• Increases in demand for greater, more complex functionality;

• Stricter (required and desirable) constraints on performance and reaction times;

• Attempts to increase productivity and reduce costs while constantly pushing requirements to the limit;

• Requirement of regular change and evolving systems.
Evolution

Any intelligent fool can make things bigger and more complex ...

It takes a touch of genius and a lot of courage to move in the opposite direction.

*Albert Einstein*
At runtime, some systems need to:

- to react to changes in the environment;
- to meet necessary constraints on the system that were not previously satisfied and possibly not previously known;
- to protect the system from external threats.

Legacy systems are those that have evolved over longer timeframes, due to:

- separate systems being combined together;
- new hardware or software technologies being used;
- new user requirements;
- new regulatory compliance requirements.

Software is not static... otherwise it would be in the hardware!
Critical Systems

- Systems where failure or malfunction will lead to significant negative consequences.
- Strict requirements for security and safety to protect the user or others.
- Critical to the organization’s mission, product base, profitability or competitive advantage.

<table>
<thead>
<tr>
<th>Automotive Systems</th>
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<tr>
<td>Medical Devices</td>
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<tr>
<td>Financial / Enterprise Information Systems</td>
</tr>
</tbody>
</table>
Current Situation

- Software is pervasive, widely used, and often invisible.
- Much legacy code, badly structured, poorly maintained.
- Many software failures, declining quality:
  - E.g., Therac 25, ARIANE 5, Mars Polar Lander, … and many more!
- Complex physical environments and diverse hardware platforms.
- Insufficient number of qualified developers and testers.
- Current techniques do not scale sufficiently and have failed to overcome 50 years of declining quality.
Evolving Critical Systems

- have evolved from legacy code and legacy systems, or
- result from a combination of existing component-based systems, possibly over significant periods of time, or
- evolve as a result of a focused and intentional change in organization and architecture to exploit newer techniques believed to be beneficial;
- they require that the system adapt and evolve at run-time in order to react to changes in the environment or to meet necessary constraints on the system that were not previously satisfied and possibly not previously known.
An Evolving Critical System must be

- described in a manner that enables the developer to understand the necessary functionality of the system (*requirements engineering*), and
- which are expressed in a clear and precise way (*formal specification*),
- and yet which offers sufficient flexibility to follow the processes and practices within the organisation or necessitated by the development process (*agile methods, software processes, software process improvement*).
Requirements Effort vs. Cost Overrun
The architecture of the system must be well understood;

- the architecture may be the basis for future decisions on changes to be made as part of the evolution process;

- this is particularly true where the system evolves at run-time (adaptive systems, autonomic computing, organic computing);

- models of the system are a key component (model driven development), which will change over time and offer insights into potential areas of difficulty and as the basis for (possibly automated) code-generation.
An ECS must be structured

- in a way that change can be controlled and clear,
- with fixed core functionality
- and then features that may be changed, adapt, and even be deleted (*software product lines*) in order to support the necessary evolution.
Determining that quality and reliability are not impaired involves

- continual overview of the development and evolutionary process (*processes and methods, process evaluation*);
- ensuring that policies and constraints are met (*autonomic computing, organic computing, adaptive systems*);
- collecting and recording data and evidence (*metrics, software process improvement*), and
- computation of a range of reliability measures at various points in time and the appropriate analysis thereof (*software reliability engineering*).
ECS Research Agenda

An ECS Research Agenda addresses several core research topics in the evolving critical systems field.

- The central research topic is building software that
- (a) is highly reliable, and
- (b) retains this reliability as it evolves, without incurring prohibitive costs.
Evolving Critical Systems

Tooling
- Plan
  - Evolve
  - Assess

PEA+T
MAPE

Source: IBM, AC Blueprint 2003
Some Examples of Lero ECS Research

1. Smarter Cities
   - In conjunction with Intel Labs Europe, Dublin City Council and IBM

2. Software Product Lines
   - Use of models to gain efficiencies

3. Adaptive Security and Privacy (Cloud, smart buildings)
   - In conjunction with United Technologies and IBM

4. Parallelisation of code to optimise use of multicore hardware
   - In conjunction with Movidius and IBM
Some Examples of Lero ECS Research

5. Architectural Recovery and Preservation
   – In conjunction with several financial services companies

6. Performance Evaluation in Large Systems
   – In conjunction with IBM

7. Autonomous Space Systems
   – In conjunction with NASA and ESA and EU FP7 Project ASCENS
An ECS Scenario

Space Exploration

- Some of the most complex and expensive software applications to date.
- High Levels of Autonomy.
- Significant consequences for failure.
Swarm Technologies

• Inspired by swarms of bees and flocks of birds in nature;

• Many application areas:
  – drug discovery;
  – communication systems;
  – environmental monitoring;
  – exploration.
Coordinated swarms of smaller spacecraft will offer:

- More effective use of solar power;
- Access to areas where large craft could not go;
- Ability to perform more complex tasks;
- Greater accuracy and flexibility.
Autonomous NanoTechnology Swarm

Using swarms of “intelligent”, autonomous spacecraft to explore

1. Lunar and Martian surface (Lander Amorphous Rover Antenna, LARA)
2. Saturn’s rings (Saturn Autonomous Ring Array, SARA)
3. Asteroid belt (Prospecting Asteroid Mission, PAM)
ANTS Concept Mission - PAM
Contributions

1. Formal Methods
2. Autonomic Computing
3. Software Product Lines
4. Automatic Code Generation
Model of Formal Method

Swarm Formal Method Model and Outline

\[ \Phi = \{ \text{SendMessage, ReceiveMessage} \} \]

is a set of (partial) transition functions where each transition function maps

\[ \text{Memory} \rightarrow \text{Input} \rightarrow \text{Output} \rightarrow \text{Memory} \]

\[ \text{memory'} = \{ \text{Goals'}, \text{Model'}, \text{CommsTracking} \} \]

<table>
<thead>
<tr>
<th>Agent State</th>
<th>Actions leading to the agent state</th>
<th>f</th>
<th>p</th>
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<tbody>
<tr>
<td>Communicating</td>
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<td></td>
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</tr>
<tr>
<td>SendMessageWorker</td>
<td>50</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>SendMessageLeader</td>
<td>50</td>
<td>2</td>
<td></td>
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<tr>
<td>SendMessageError</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ReceiveMessageWorker</td>
<td>50</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>ReceiveMessageLeader</td>
<td>50</td>
<td>2</td>
<td></td>
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<tr>
<td>Reasoning</td>
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<tr>
<td>ReasoningDeliberative</td>
<td>50</td>
<td>2</td>
<td></td>
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<tr>
<td>ReasoningReactive</td>
<td>50</td>
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<tr>
<td>Processing</td>
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<tr>
<td>ProcessingSortingAndStorage</td>
<td>17</td>
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<tr>
<td>ProcessingGeneration</td>
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<td>2</td>
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<tr>
<td>ProcessingPrediction</td>
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<td>ProcessingDiagnosis</td>
<td>16</td>
<td>2</td>
<td></td>
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<tr>
<td>ProcessingRecovery</td>
<td>16</td>
<td>2</td>
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<tr>
<td>ProcessingRemediation</td>
<td>17</td>
<td>2</td>
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</tbody>
</table>

\[ \sum_{\delta^i} + m\phi^i = \sum_{\delta^i} = m\phi^i + m\phi^i \]

\[ n\phi^i = (n + m)\phi^i = m\phi^i + m\phi^i \]
AEIP {
    MESSAGES { ... } 
    CHANNELS { ... } 
    FUNCTIONS { ... } 
    MANAGED_ELEMENTS {
        MANAGED_ELEMENT worker {
            INTERFACE_FUNCTION getDistanceToNearestObject { RETURNS { DECIMAL } }
        }
    }
} // AEIP

METRICS {
    METRIC distanceToNearestObject {
        METRIC_TYPE { RESOURCE }
        METRIC_SOURCE { AEIP.MANAGED_ELEMENTS.worker.getDistanceToNearestObject }
        DESCRIPTION { "measures the distance to the nearest space object" }
        MEASURE_UNIT { "KM" }
        VALUE { 100 }
        THRESHOLD_CLASS { DECIMAL [0.001 ~ ] }
    }
}
Autonomic Computing

Inspiration from the human/mammalian autonomic nervous system.

Fight or Flight

sympathetic
(SyNS)

Rest and Digest

parasympathetic
(PaNS)
Autonomic Environment

Autonomic Communications Channel

I am healthy
I am alive

Stay awake

I am alive

sSleep

AE

MC

AM

S*

S*

S*

Zzz

I am healthy
SPL / Feature Model

If father present, the heir is:

- Mandatory
- Optional

<table>
<thead>
<tr>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layer 3</th>
<th>Layer 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-Protection</td>
<td>Move</td>
<td>Send Data Earth</td>
<td>Explore and Discover</td>
</tr>
<tr>
<td>Avoid Crashing</td>
<td>Walk</td>
<td>Evaluate Interest</td>
<td>Analyse</td>
</tr>
<tr>
<td>Avoid run a out of power</td>
<td>Inform objective</td>
<td>measure image</td>
<td></td>
</tr>
<tr>
<td>Protect from solar storms</td>
<td>Search new objective</td>
<td>measure X-ray</td>
<td></td>
</tr>
<tr>
<td>Gas prop.</td>
<td>Use Sail to Orbit and flight</td>
<td>Digital Camera</td>
<td></td>
</tr>
<tr>
<td>Switch off sub-sytems</td>
<td>Use sail as a shield</td>
<td>Optical Camera</td>
<td></td>
</tr>
</tbody>
</table>

Abstraction Layer 1
Abstraction Layer 2
Abstraction Layer 3
Abstraction Layer 4

Dependency

Explore Universe

Explore

Universe

Explore and

Discover

Set Objective

and Approach

Flight

Search

new

objective

Inform

objective

Evaluate

Interest

Avoid

Crashing

Avoid run a out of power

Protect from solar storms

Measure solar storms

Switch off sub-sytems

Use sail as a shield

Gas prop.

Use Sail to Orbit and flight

Snake

Amoeba

Rolling

Digital Camera

Optical Camera

Dependency

If father present, the heir is:

- Mandatory
- Optional

Only one of them

At least one of them

Dependency
Requirements to Design to Code (R2D2C)

- Requirements expressed as scenarios
  - (reversed)
  - Mathematical laws of concurrency

- Models
  - Existing code generating tools
  - Existing model extraction (reverse engineering) tools

- Code
Current Status
Benefits of the Method

• Automation of entire development process;
• Significant increase in quality;
• Ability to do formal proof on properties of implementations;
• Ability to do formal proof of correctness;
• Automated means for requirements analysis;
• Guaranteed correspondence between requirements and their implementation as code.
Applications

• End-to-end automatic code generation of provably correct systems;
• Automatic reimplementation after any requirements change;
• Exploiting re-use across platforms;
• Reverse engineering legacy systems to a mathematically sound model;
• Analysis and documentation of existing systems (e.g., expert systems);
• Re-engineering of legacy systems to a provably correct new implementation.
Domains (to date)

- Agent Based Systems;
- Wireless Sensor Networks;
- ANTS;
channel brakerelease, brakeset, stabilize, wfctoolaquire : T ;
GA = brakeset ! 0 -> GA ;
DRone = brakeset ? x -> brakerelease ! 0 -> stabilize ! 0 -> brakeset ! 0 -> DRone ;
DRtwo = brakeset ? x -> wfctoolaquire ! 0 -> brakeset ! 0 -> DRtwo ;
System = DRone || || || DRtwo || || || GA ;
Transaction boltrelease = new Transaction(2);
Transaction brakeset = new Transaction(2);
Transaction stabilize = new Transaction(2);
Transaction wftoolaoquire = new Transaction(2);
GA GA_init = new GA(brakeset);
DRone DRone_Init = new DRone(boltrelease, brakeset, stabilize);
DRtwo DRtwo_Init = new DRtwo(boltrelease, brakeset, wftoolaoquire);
DRone_Init.start();
DRtwo_Init.start();
GA_Init.start();

EXECUTING:

brakeset
brakeset

DEADLOCK DETECTED
Caveat
Conclusions

• Software must evolve.
• There is a tension between reliability, predictability and cost and this need for evolution.
• There is a need for an Evolving Critical Systems research effort.
• Lero and others are driving that effort.
Any problem in computer science can be solved with another layer of indirection.

But that usually will create another problem.

David Wheeler
Go raibh maith agat!
Thank you!
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