Systems of Systems and Statically Defined Dynamic Architecture Evolution

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Introduction

- Context: NASA Manned Space exploration
  - Earthbound control center no longer feasible
  - Will need control center and other systems onboard
  - Will need to dynamically evolve the systems of systems
- Systems of components
  - Compositions of components
  - Component interaction
  - Component and system/architectural evolution
  - Typically single thread of execution
- Systems of Systems
  - Compositions of Systems of components
  - Systems interactions
  - Systems of Systems and architectural evolution

Research Background

- Simulation language and System
  - NASA specific, but sufficient to task
  - Governed by a very flat architecture/design description
    - For components
    - For interactions
    - For topology
    - For scheduling
  - Automatically generates simulation system and schedules
  - Provides execution and visualization environment
- Goals of research
  - Reverse engineer existing simulations to create architecture models
    - SDP – an analysis tool for reverse-engineering exisiting flat simulation descriptions to provide
      - ✓ Relationship descriptions
      - ✓ Visualizations of the concrete architecture of the simulation
  - Create architecture model and support to create simulations via architecture descriptions
    - *Archpad* – a graphical architecture modeling system
      - ✓ Tailor to creating simulation architecture models
      - ✓ Basis for generating simulations

Abstract Architecture Model

- Model consists of three abstract constructs
  - Arch-element
    - A component (data or processing) or a connector
  - Arch-composition
    - Represents the substructure of an arch-element
  - Arch-region
    - An arbitrary collection of arch elements
    - Arch-regions may overlap, contain or be contained in other arch-regions
- Arch-element is the basic architecture component
  - Arch-element =

    (name,
      {service-specifications},
      {general-constraints},
      {dependency-specifications}
)
- General constraints apply to the arch-element as a whole

Abstract Architecture Model

- An arch-composition is a set of elements together with mappings as to how they relate to each other
  - Arch-composition

    (name,
    {arch-elements},
    {mappings}
)
  - Mappings accomplish several things
    - Map an sub-arch-element service-specification to the arch-element service specification
      - ✓ ie, indicate which service specifications are used to satisfy the arch-elements interface
    - Map internal satisfaction of dependency-specifications to their associated service-specifications
    - Map unsatisfied service-specifications to the arch-element interface specification
    - Map general-constraint satisfaction
    - Map unsatisfied general-constraints to the arch-element interface

Elements in the Simulation World

- Basic and composite elements
  - May be both depending on use in a particular architecture configuration
    - In one simulations may be treated as a basic component (eg, the Crew Exploration Vehicle - CEV)
    - In another it may be that we need to consider its constituent component (CEV as stage 1 rockets and astronaut capsule, eg)
- Basic architecture elements are physical objects
  - Such as the CEV or earth
- Basic elements are active or passive
  - Eg, the CEV is active, earth passive
  - Passive elements often contexts for active elements
  - Passive elements often sources of constraining influences on active objects (as the earth is on the CEV, eg)

Elements in the Simulation World

- A product line style-like organization
  - Commonality: architecture components used in a variety of simulations
  - Variability: architecture components specifically for certain simulations
- Schedules are critical for simulations
  - Envisioned as a general-constraint
  - Also for real-time systems
  - Schedules for various levels of the simulations
    - Micro-level schedules for individual components
    - Macro-level schedules coordinating multiple components
    - Over all schedules governing sequencing phases of a simulation
- Motivation for the notions of *configurations*
  - Specific physical events when the "world" changes
    - Eg, failures, transitioning from earth to space
    - Eg, de-coupling the rocket stage from the capsule
    - Eg, docking at the space station
  - May need to represent sequences, trees or graphs of events

Specializations of AAM

- Architecture Transition Connectors
  - Define the interactions between architectures
  - Governs the transition of control and data between architectures
- Graphs of architectures represent a (projected) history of the simulation
  - Sequences represent sequences of events
  - Trees represent sequences of events that include choices
  - Graphs represent sequences of events with choices/merges
- An architecture of architectures graph (AAG) represents a complete simulation
  - Arch-archs-graph =

```
( name,
  {arch-configurations}
  {thread-bindings}
  {schedules}
)
```

Specializations of AAM

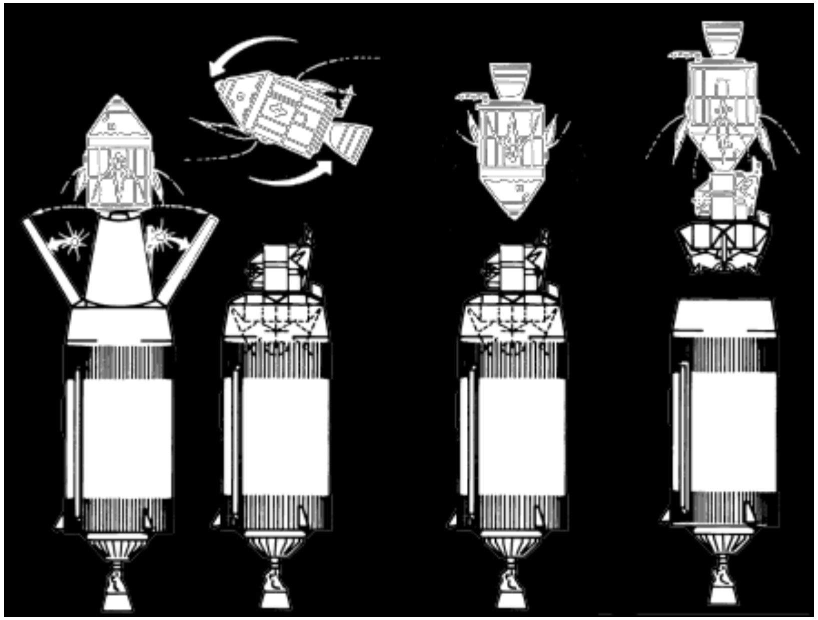
- The thread bindings of an ACG
  - Tie individual AC threads together across the architectural configuration graph
    - Some threads stop executing
    - Some threads continue
    - Some threads start up
  - Defines the actual execution of threads where the AC threads bindings merely define the potential threads in a configuration
- Schedules in an ACG
  - Define when the ACs begin and end
- Execution semantics assumptions wrt data:
  - All data is "current" with in a thread
  - No "own" data
  - Shared data between threads is "read only"
  - If want writeable "global" data, need critical sections

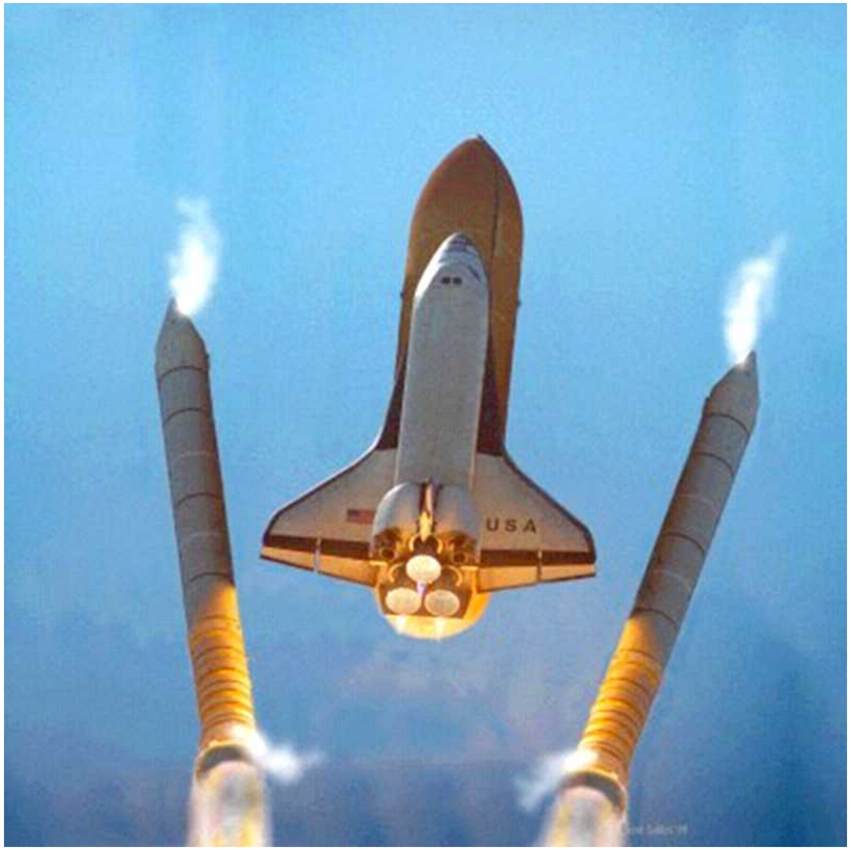
Architecture-of-Architectures

- Problem domain: NASA M.E. simulators
  - Exhibit a varying architecture as simulated vehicles reconfigure in-flight
  - Each architecture describes the simulator and simulated system over an interval of time
  - Architectures share common sub-architectural elements
  - An architecture-of-architectures approach allows common elements to be defined once
  - Changes to one element propagate to all architectures

Dynamic Architectural Change

- Examples of architectural change from Apollo and Shuttle





Relationships Among Sub-architectures

- Most sub-architectures are the product of a physical transformation of an existing architecture
  - Differences tend to be incremental derivations
  - Substantial redundancy exists among sub-architectures
- Long duration missions will exhibit many sub-architectures requiring considerable effort:
  - In development of sub-architectures
  - In maintenance of sub-architectures

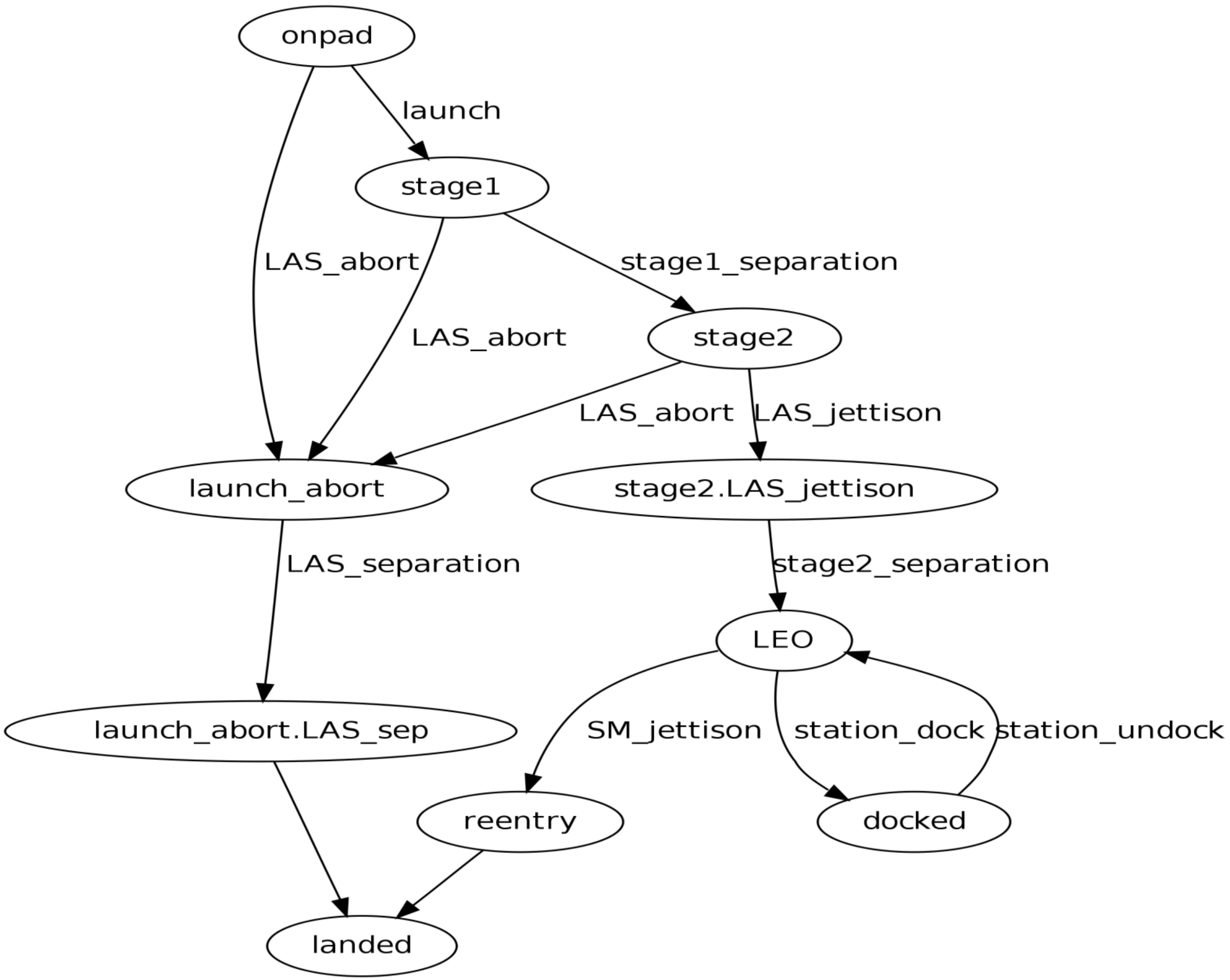
Architectural Transitions

- To avoid development and maintenance of highly redundant sub-architectures we propose connectors among sub-architectures: architectural transitions
  - Transitions describe how one sub-architecture differs from another
  - Descriptions can be minimal—they describe one temporal change exhibited by a vehicle in flight
- Transitions are reusable—they can be applied to more than one source architecture

Architectural Transitions

- Architectural transitions reduce redundancy
  - Potentially, only the initial vehicle configuration has a full sub-architectural description
  - Other sub-architectures are derived by applying transitions to the initial and derived architectures
- Example:
  - Initial configuration, vehicle on-pad (pre-launch)
  - A transition describes differences from post-launch configuration
  - Another transitions describes changes incurred by stage 1 booster separation

Example Architecture Graph



Elements of a Transition

- Transition predicate and effector function
- Predicate:
  - Selects architectures valid for application of the transition
  - Iff the predicate of transition t holds for some sub-architecture c, then there is another sub-architecture c' defined by the application of the effector function of t to c.

Elements of a Transition

- Effector function:
  - Defines a sub-architecture as a variation on an existing sub-architecture
  - Captures only the differences between a source architecture and a derived architecture
  - May not be idempotent
- A single transition may apply to more than one source architecture
  - Increases transition complexity but reduces redundant specification
  - Example: the launch abort transition can be initiated from multiple vehicle configurations

Implementation

- Implemented with an architectural meta-language
- Currently utilizes a procedural description
- Meta-language will allow non-procedural descriptions
- Currently, predicate and effector computations are not separated

Example Transition

- conf: architecture to be transformed
- rename(): Provides a name for derived
- return(); Provides a predicate value. Predicate holds if true
- replace(): Carries out a transformation on conf

```
transition stage1_separation {
    global var conf;
    conf = rename(conf, stage2);
    if (!has_component(conf, fullstack)) return(false);
    if (has_constraint(conf, onpad)) return(false);
    conf = replace(fullstack, {..stack_stage_two, ..stage1});
    return (true);
}
```

Summary

- Began with our abstract architecture model
  - Useful for modeling architecture elements in simulations
  - Schedules for individual architecture elements describable as constraints on the elements
- Initial extensions to model needed
  - Differentiation of data, processing and connecting elements?
  - Further development of connecting elements beyond typical use
- To model complex simulations where physical changes take place, propose the ideas of architecture configurations and configuration graphs
  - Notions of locus of control, threads
  - Higher levels of scheduling
  - Binding and rebinding of data
  - Binding of threads to actual execution threads