
Please stand by

Automating System Assembly of Aerospace Systems

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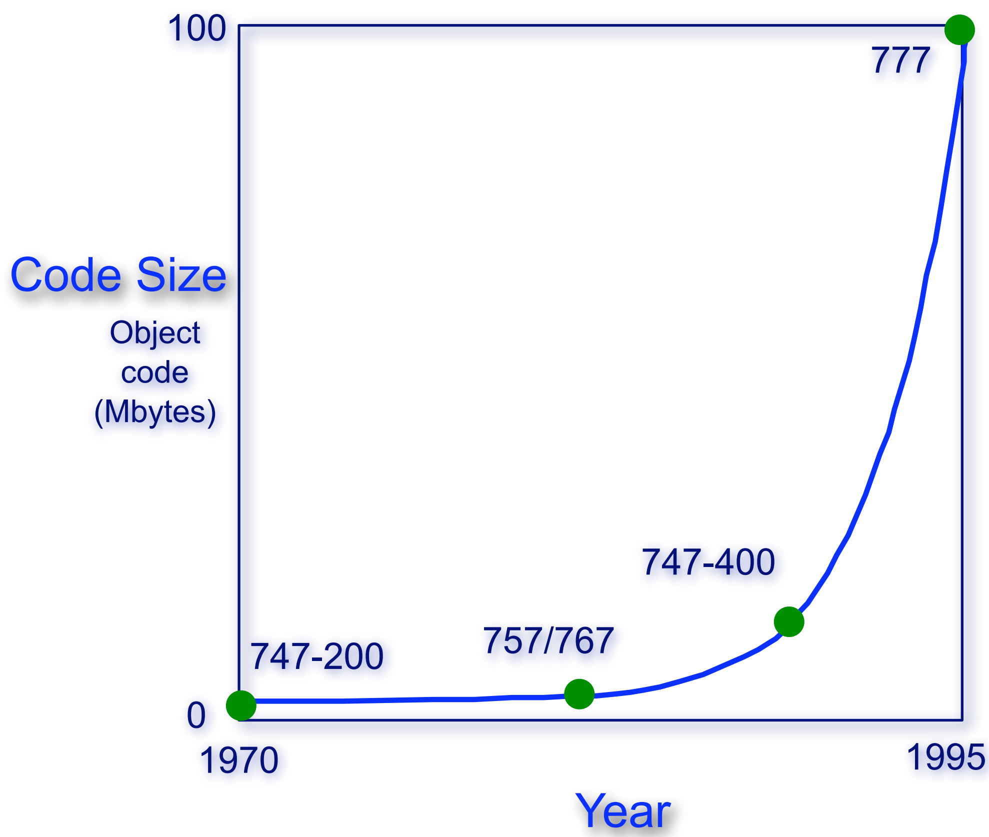
LANGLEY FORMAL METHODS

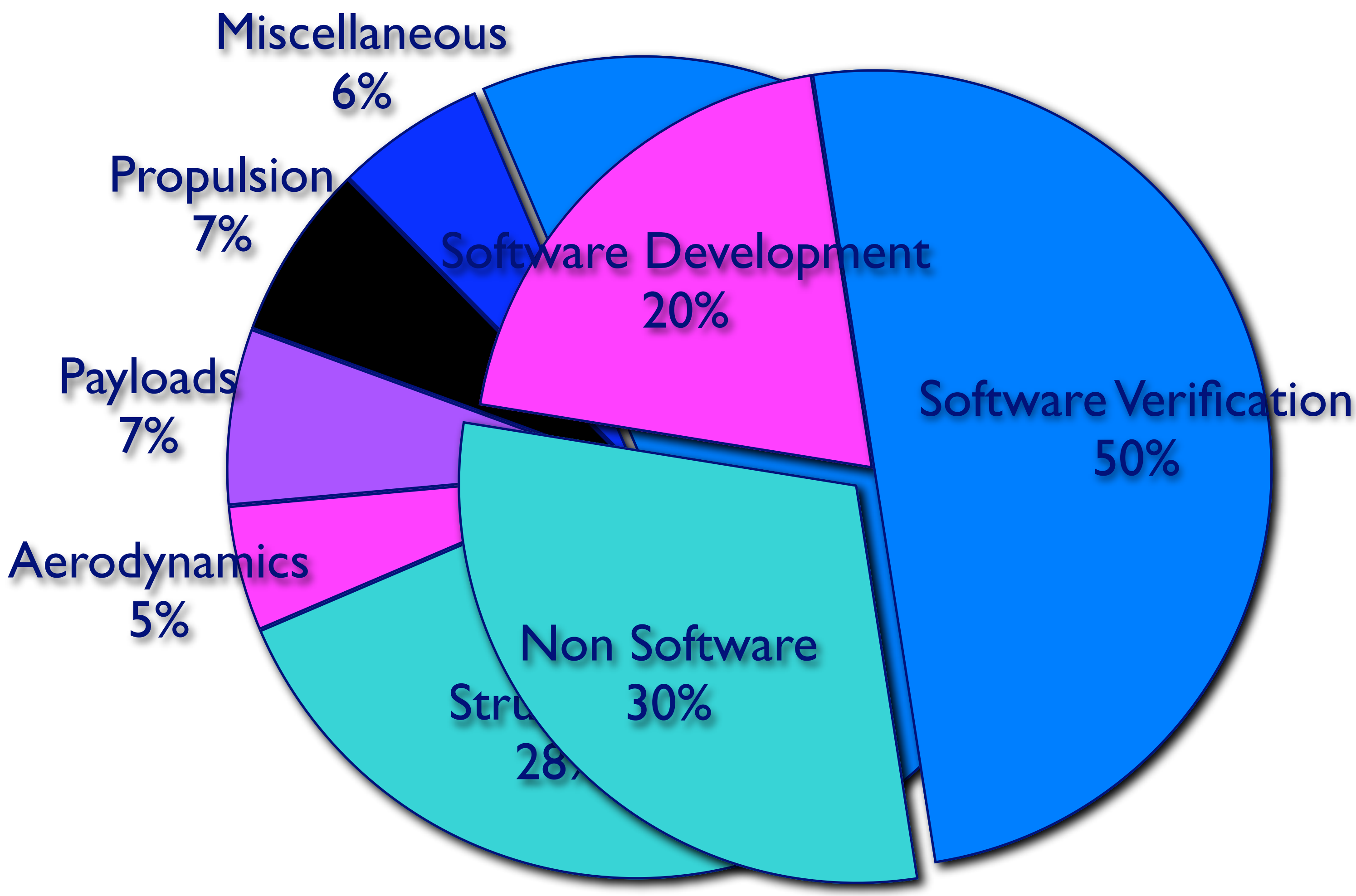
Newport News, VA

April 2008

Commercial Air Transport



Air Transport Development Costs



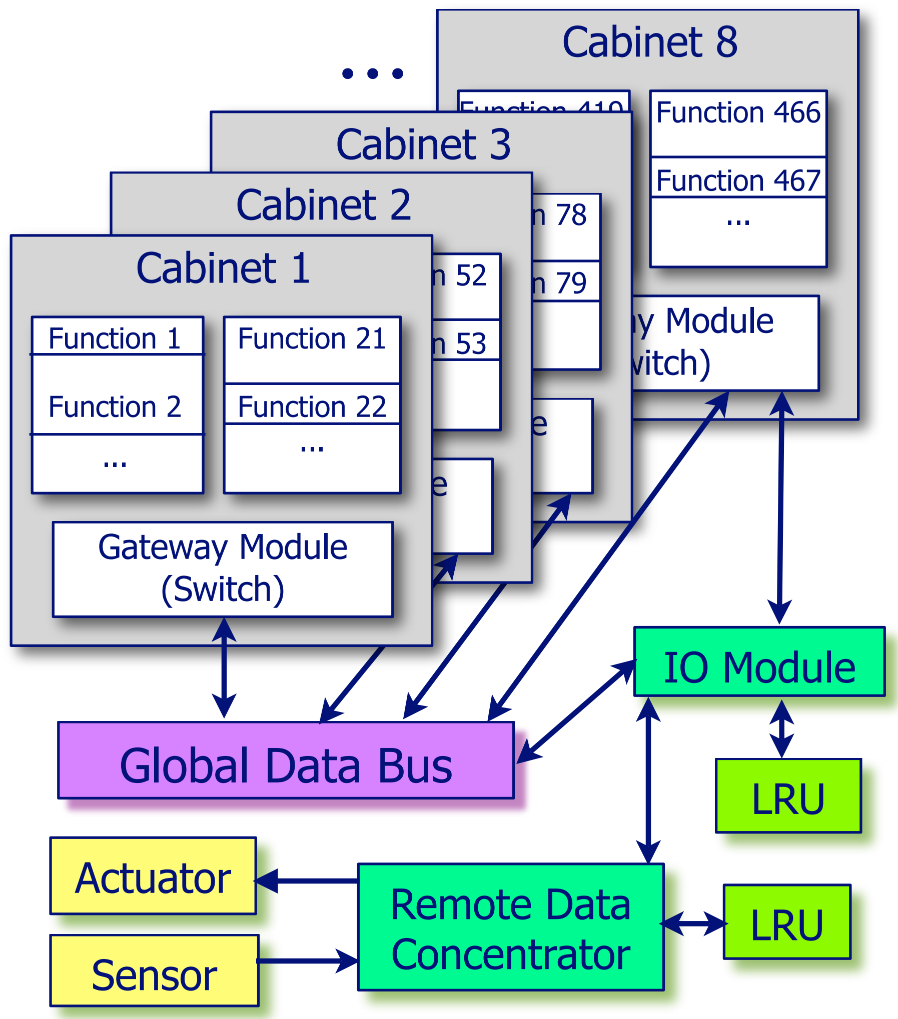
Is Boeing a Software Company?

- Software development and verification account for 1/3 cost
  - Important to build reliable, dependable commercial avionics systems
  - The industry is heavily regulated by the FAA
- The military side is also very dependent on software
  - 1960 - 8% F4 fighter capability came from software
  - 2000 - 85% F22 fighter capability provided by software
  - Even more now

- Boeing's core competence is system integration
  - New business model
  - Dependent on large network of suppliers, globally distributed

Integrated Modular Avionics

- Past: federated systems
- IMA: shared resources
- COTS components
- Multiplexed communication
- Smaller, lighter, cost-effective components
- Powerful computer processing modules handle multiple apps
- Cabinets are connected to global data bus, IO modules, LRUs, sensors, actuators, etc.
- Integration, configuration, assembly?



Component-Based System Design

- Goals of CBSD
  - Construction of systems from independent components
  - Use of commercial-off-the-shelf (COTS) components
  - Separation of concerns
  - Decrease risk, system complexity, development time & cost
  - Increase reliability, malleability, and flexibility
- Domain-specific challenges
  - System architecture
  - Interface definitions
  - Trusted infrastructure
  - Problem domain decomposition
  - …

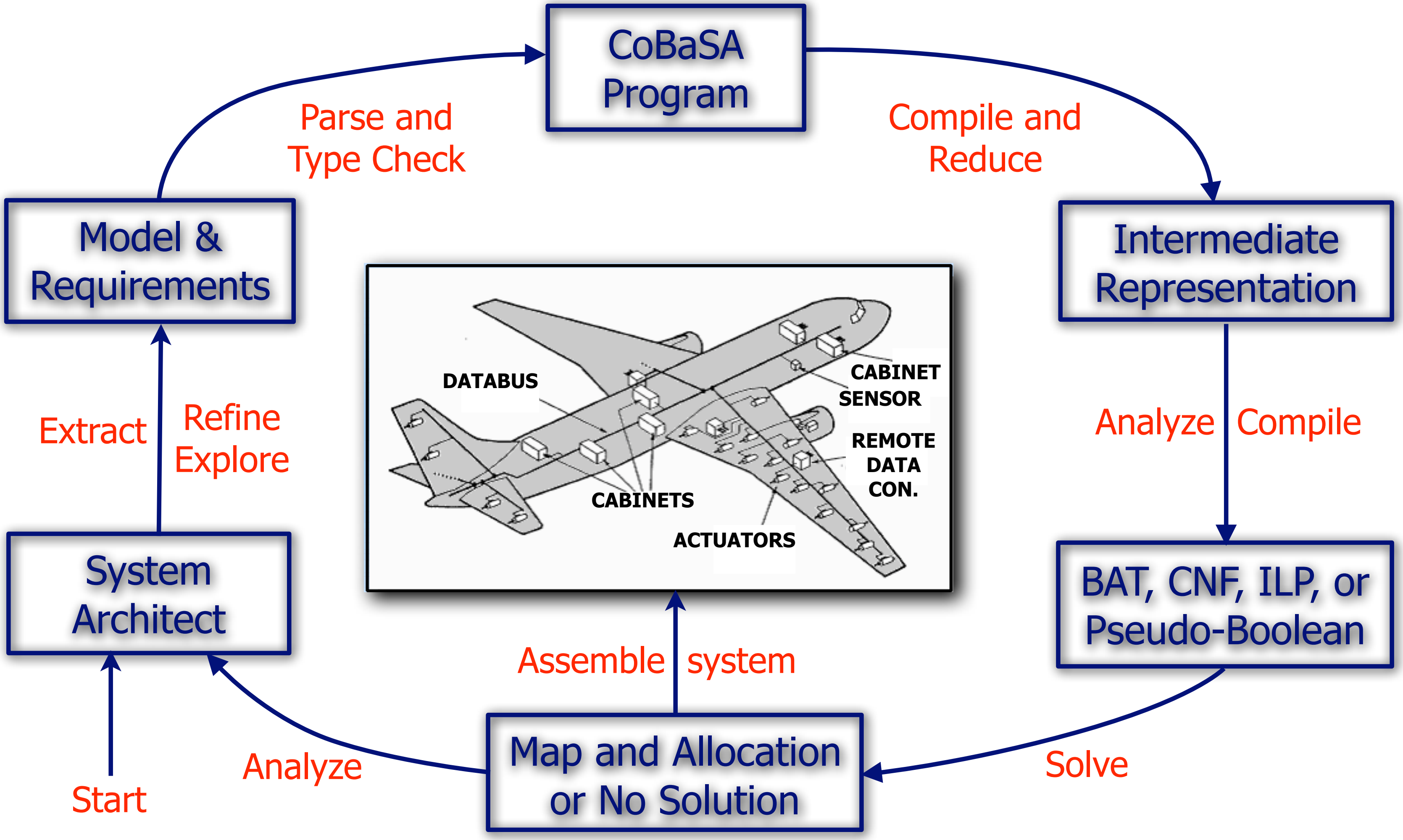
System Assembly

- The general challenge is the system assembly problem:
  - From a pool of available components,
  - Which should be selected &
  - How should they be connected, integrated, assembled
  - So that system requirements are satisfied?
- Currently this is application specific and labor intensive
- Our focus is on automation
  - Algorithmically find optimal solutions directly from requirements
  - Insight: We can reduce system assembly to a satisfiability question
  - Does there exist a way of selecting & assembling components that satisfies the system requirements?

CoBaSA System

- Developed CoBaSA: Component-Based System Assembly
- An object-oriented modeling language
- A declarative constraint language
- Assembly is solved using formal verification technology
- Used CoBaSA to solve actual Boeing problems

Assembly of Avionics Systems



Outline

Motivation

System Assembly

CoBaSA Language

CoBaSA Constraint Solving

Case Study

Conclusions and Future Work

CoBaSA Modeling Language

- Needed complete control of syntax and semantics
- Developed our own language
- Object-oriented language
- Functions as a target language
- This is what we did with the Boeing project

CoBaSA Data Types

- Basic data types:
  - Booleans
  - Strings
  - Integers & integer ranges
  - Enumerated data types
- Complex data types include:
  - Recursive data types
  - Entities (classes)
  - Multidimensional arrays

CoBaSA Language: Entities

```
entity server {
  ;id string
  ;ram-available int
  ;cpu-time-available 10000
  ;secure bool
}
```

```
entity process {
  ;id string
  ;ram-req int
  ;cpu-time-req int
  ;sec-req bool
}
```

```
entity linux-server extends server {
  ;max-num-procs int
  ;neighbor linux-server
}
```

CoBaSA Language: Maps

- Variable declarations

```
var linux-server[20] linux-servers =
      [ { ;120 ; ;"LS-001" ;1024 ; ;False}, …
        { ;80 ;ls[2] ;"LS-020" ;512 ; ;True}]

var process[500] processes = ...
```

- Objects can be assigned values, but write-once memory

```
assign linux-servers[0].neighbor = linux-servers[19]
```

- Map constraints: map consumers to resource providers

```
map proc-serve processes linux-servers
```

- Field constraints: specify dependence between consumer and resource fields

```
constraint proc-serve ((ram-req, cpu-time-req))
                      ((ram-available, cpu-time-available))
```

CoBaSA Language: Constraints

- Arbitrary Boolean & relational constraints
- Boolean expressions with map references
- Relational arithmetic expressions
- Quantification: universal and summation

```
For_all p in processes
   For_all s in linux-servers
      (proc-serve(p,s) and p.sec-req) implies s.secure
```

- Preprocessing w/ Lisp code: (let ((v1 a1) … (vn an)) <lisp code>)

```
For_all s in linux-servers
   Sum p in processes proc-serve(p,s)
   <= (let ((v1 s.max-num-procs))
          _(floor (* 0.75 v1))_)
```

More CoBaSA Constraints

- Optimization
  - An objective function can maximized or minimized
- Interdependent maps
  - Result of one map affects the result of another map
  - Arise from hierarchies of resource/consumer relationships
- Examples of generalized notion of maps
  - To express relation, r, over A, B: map >= 0 r A B
  - 2-function, f, from D to R: map = 2 f D R

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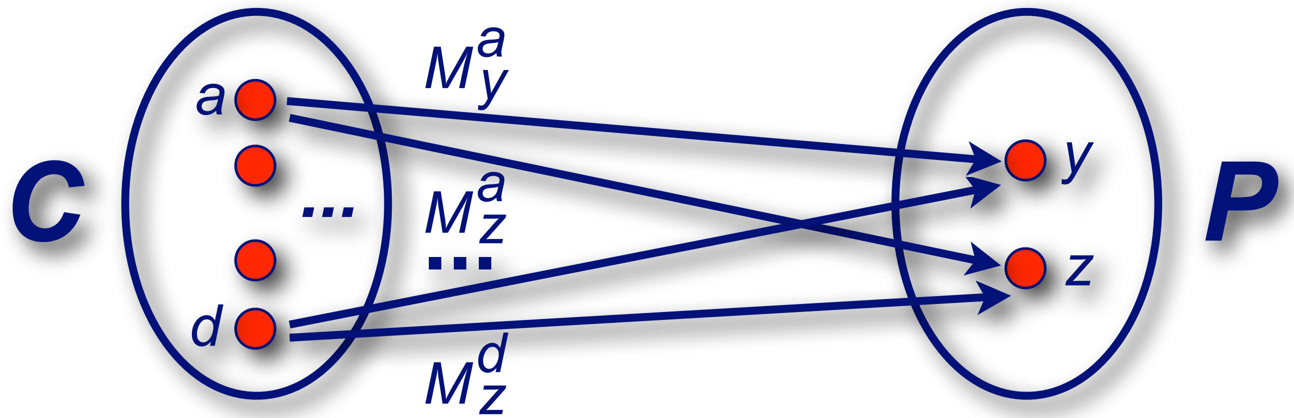
CoBaSA Constraint Solving

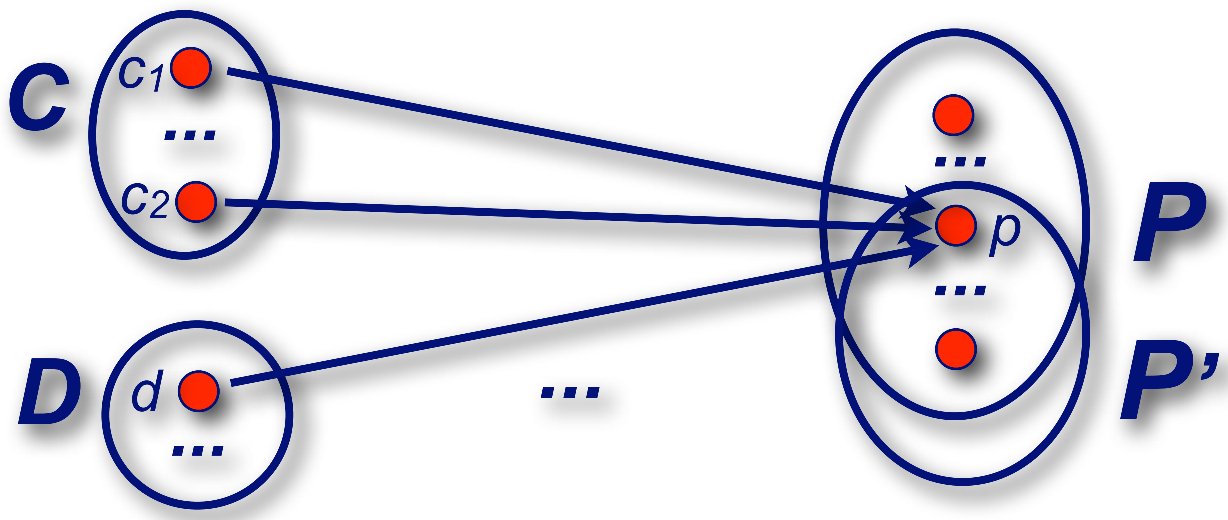
- CoBaSA programs are reducible to 0-1 integer programming
- Also known as pseudo-boolean SAT problems
  - Linear constraints of the form $\sum_{i=1}^{n} c_i x_i \ R \ c$
- For each map $M : C \rightarrow P$, we have an implicit constraint that elements of *C* map to elements of *P*



- For each *c* in *C*: $\sum_{p \in P} M_p^c = 1$

Solving Field Constraints

- We have to guarantee that *p* can provide resources for every consumer, *c*, mapped to *p*



- We express the above using pseudo-boolean constraints
- And we continue with a sequence of such transformations

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Case Study: Boeing

- Models developed over several years
- The models are complex; they include:
  - I/O time
  - Latency
  - Network jitter
  - Context switching time
  - Cache flushing time
  - Memory latencies
  - Thousands of constraints
- Based on worst-case execution time
- Models are over 500K in size

Evaluation of Case Study

- Given collection of models from simple to complete
- No feasible solution was previously known
- Even the very simple, initial models:
  - Takes 3 person-weeks to describe problem & check solution
  - **Much** longer to solve with previous approaches
- We solve simple models in seconds
- We can solve the most complex models in minutes
- Allowed Boeing "to solve, in person-weeks, problems that were previously taking person-years"
- Flexible enough to accommodate what Boeing described as "serious architecture changes"

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Summary

- Introduced the notion of system assembly
- Showed how to automatically solve system assembly problems [MSV'07,SAT'07,CAV'07]
- Developed CoBaSA system
  - Object oriented modeling language
  - Declarative constraint language
  - Decision procedure
- Showed the effectiveness and applicability of our work by solving problems arising in design of Boeing Dreamliner
- Can solve problems previously taking person-years

Future Work

- Algorithmic extensions
  - Hierarchical refinement (a component is a collection)
  - Better decision procedures
- Design support
  - If assembly is not possible, why not?
  - Threat analysis: what will drastically affect solution landscape?
- Adaptive assembly
  - Can we assemble & reconfigure in real time?
  - In response to system failure? account environmental factors?
  - Changes in mission priorities? response to invalid assumptions?
  - Under extreme conditions (low power, long latencies, …)
- Scheduling, power, weight, geometry, … .