TMT
Thirty Meter Telescope

NASA

A Model-Based Approach to Error Budgeting using SysML

Using OMG SysML for performing error accounting for complex systems

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Outline

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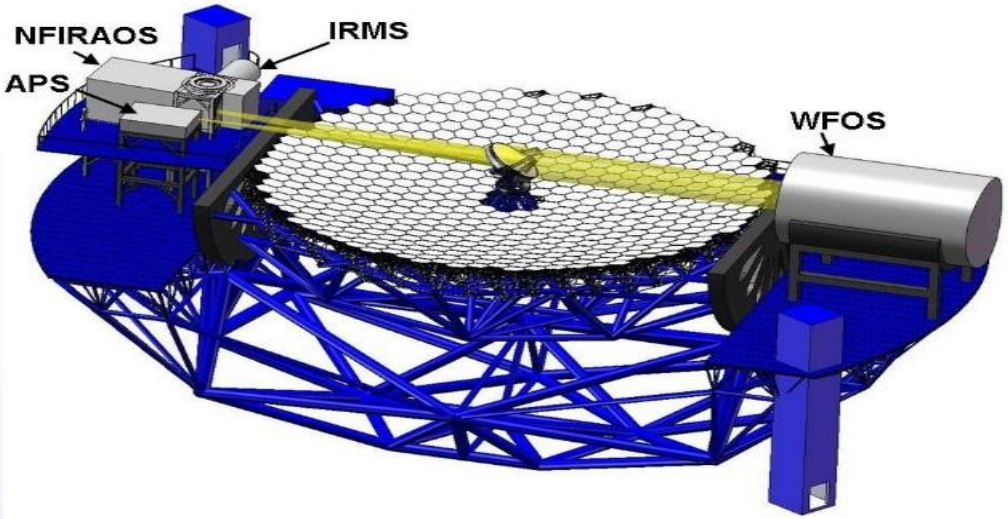
- Motivating Example
- Error Budgeting in SysML
  - Error Breakdown Tree
  - Error Roll-Up Pattern
  - Tying to Requirements & Product Breakdown Structure
- MagicDraw Customizations
- Summary & Conclusions

Context

- Alignment and Phasing System (APS)
  - Sensor responsible for measuring the pre-adaptive optics wavefront quality
  - APS (and AO) team uses MBSE with SysML to analyze requirements, produce design, and perform analysis



Error Budgeting & Error Analysis

- Track how accurate expected system performance will be compared to the requirements

- Error budgeting:
  - Flow down requirements and allocations
  - Roll-up capabilies or Current Best Estimates (CBE)
  - Track margins and reserve
    - Examples: Mass, Power, Throughput, timing, Pointing Alignment, measurement errors, performance

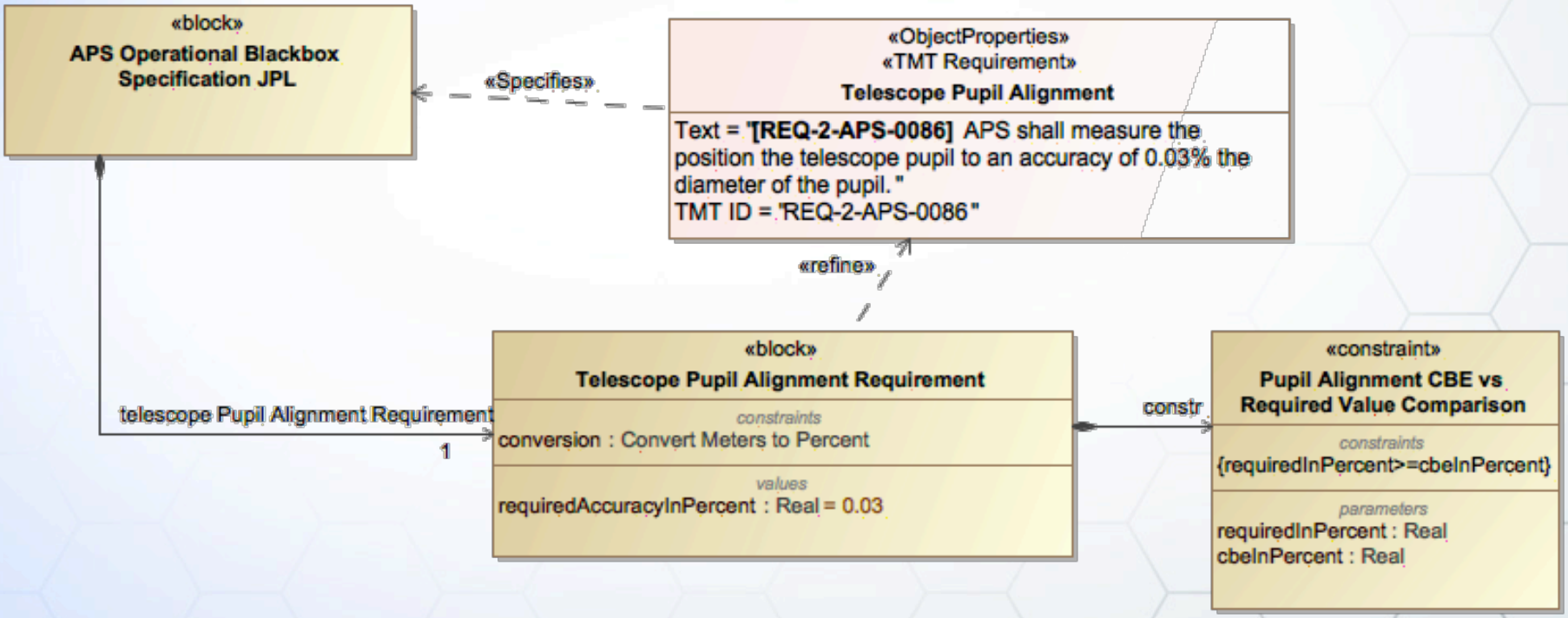
Challenges

- Error budget analysis involves multiple, related artifacts:
  - Requirements ← required accuracy
  - System design ← current best estimates, parameters
  - Error decomposition ← roll-up definition

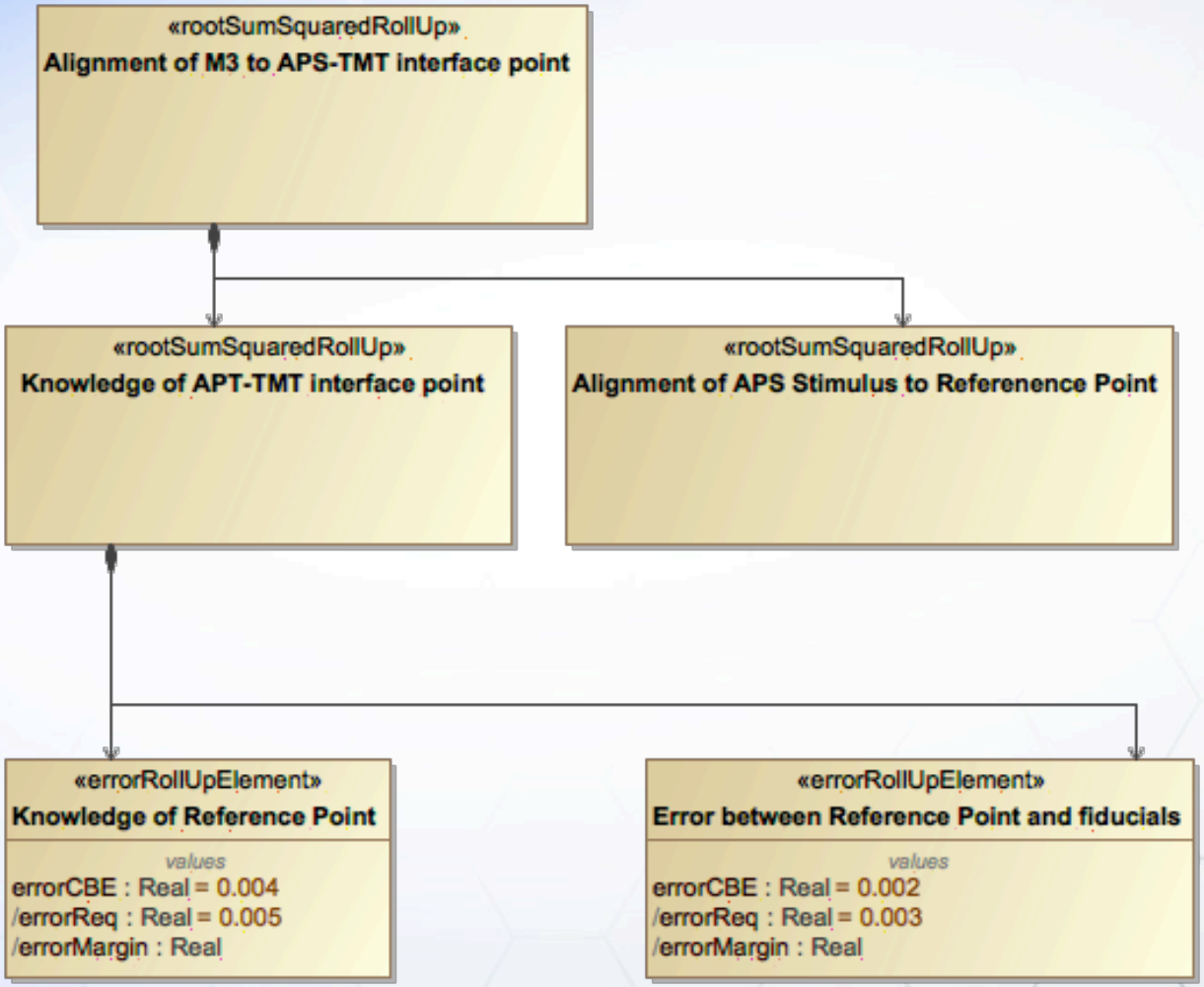
- CBEs of errors *characterize* errors on properties of the system
- Decomposition of error != product breakdown structure
  ➔ Related, but different hierarchies

Motivating Example

- M3 to APS-TMT interface pupil alignment error: "*APS shall measure the position of the telescope pupil to an accuracy of 0.03% of the diameter of the pupil.*"

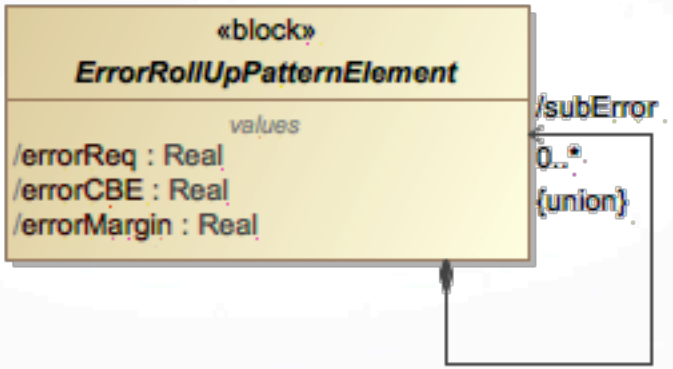


Error Budgeting in SysML: Error Breakdown Tree (Excerpt)



Error Roll-Up Pattern

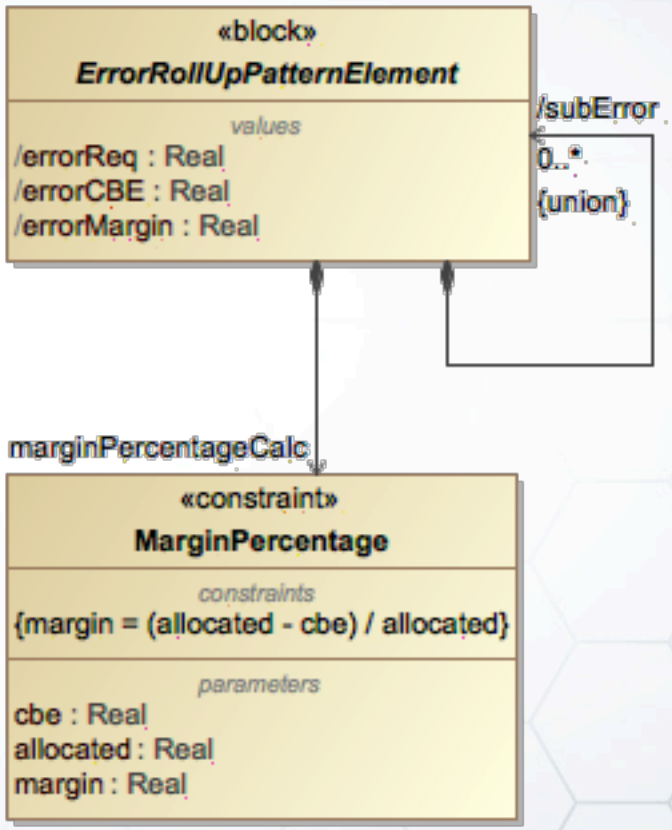
- Similar to mass roll-up pattern



Margin Calculation

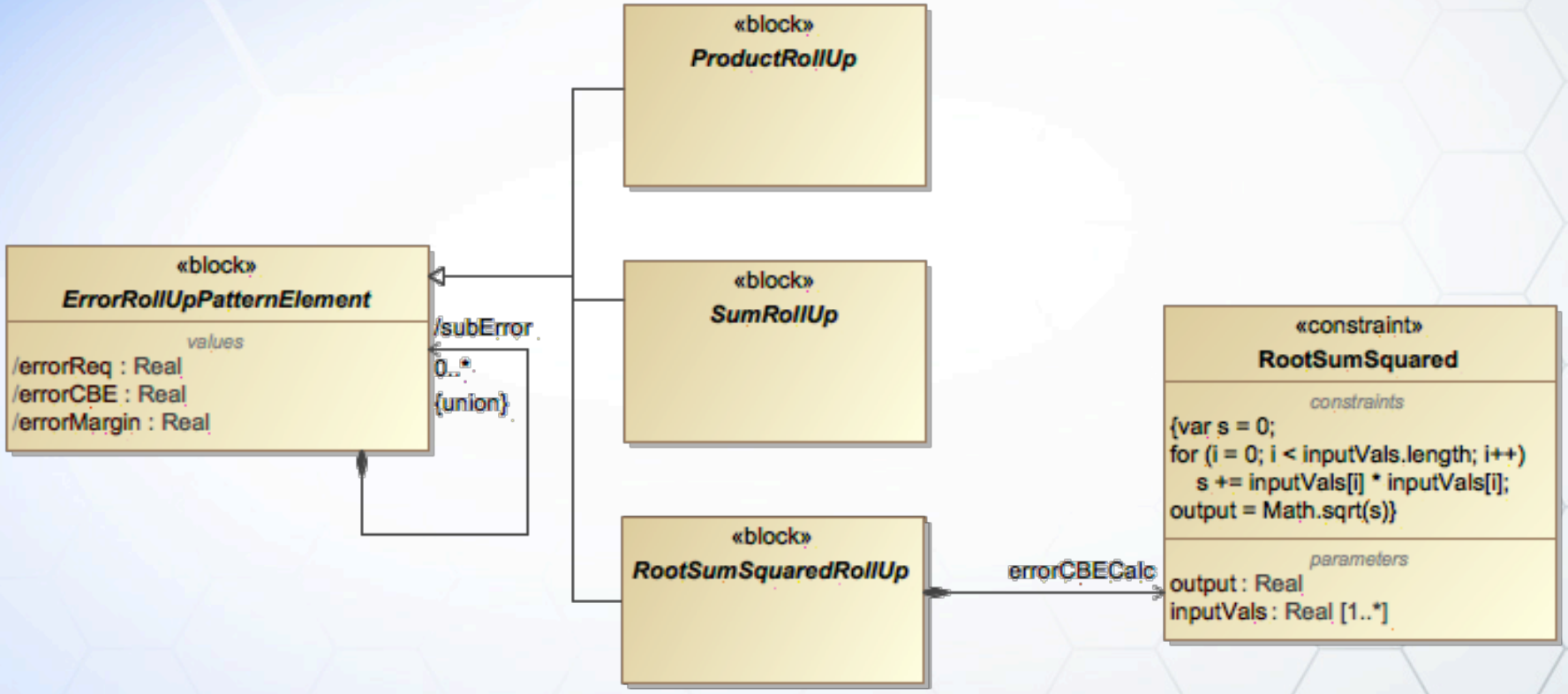
- Margin depends only on CBE and and allocation

$$margin = allocated - cbe / allocated$$



Error Roll-Up Types

- Different roll-up calculations depending on context



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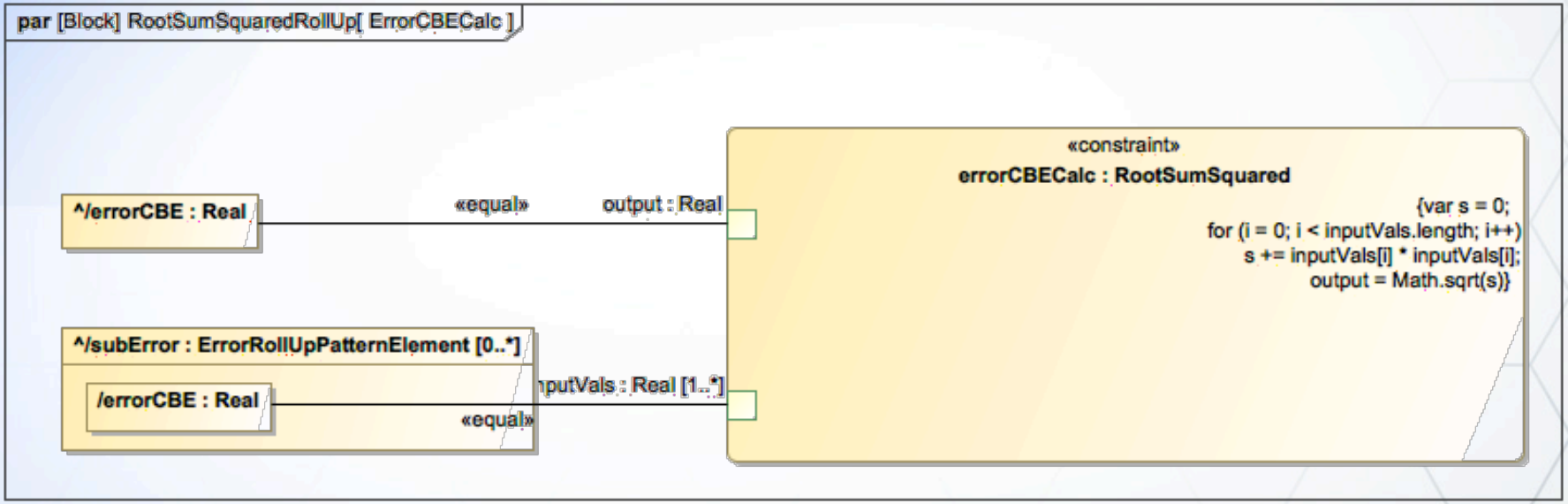
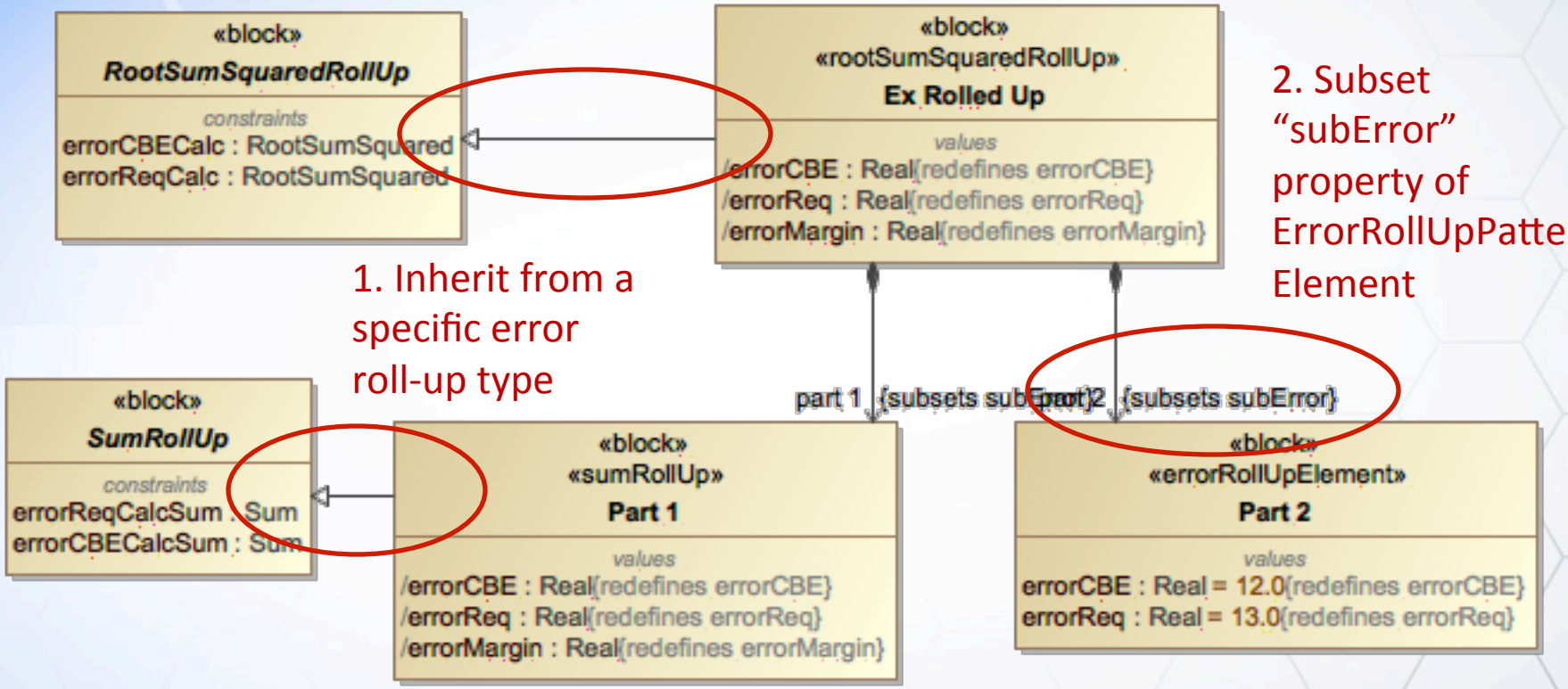
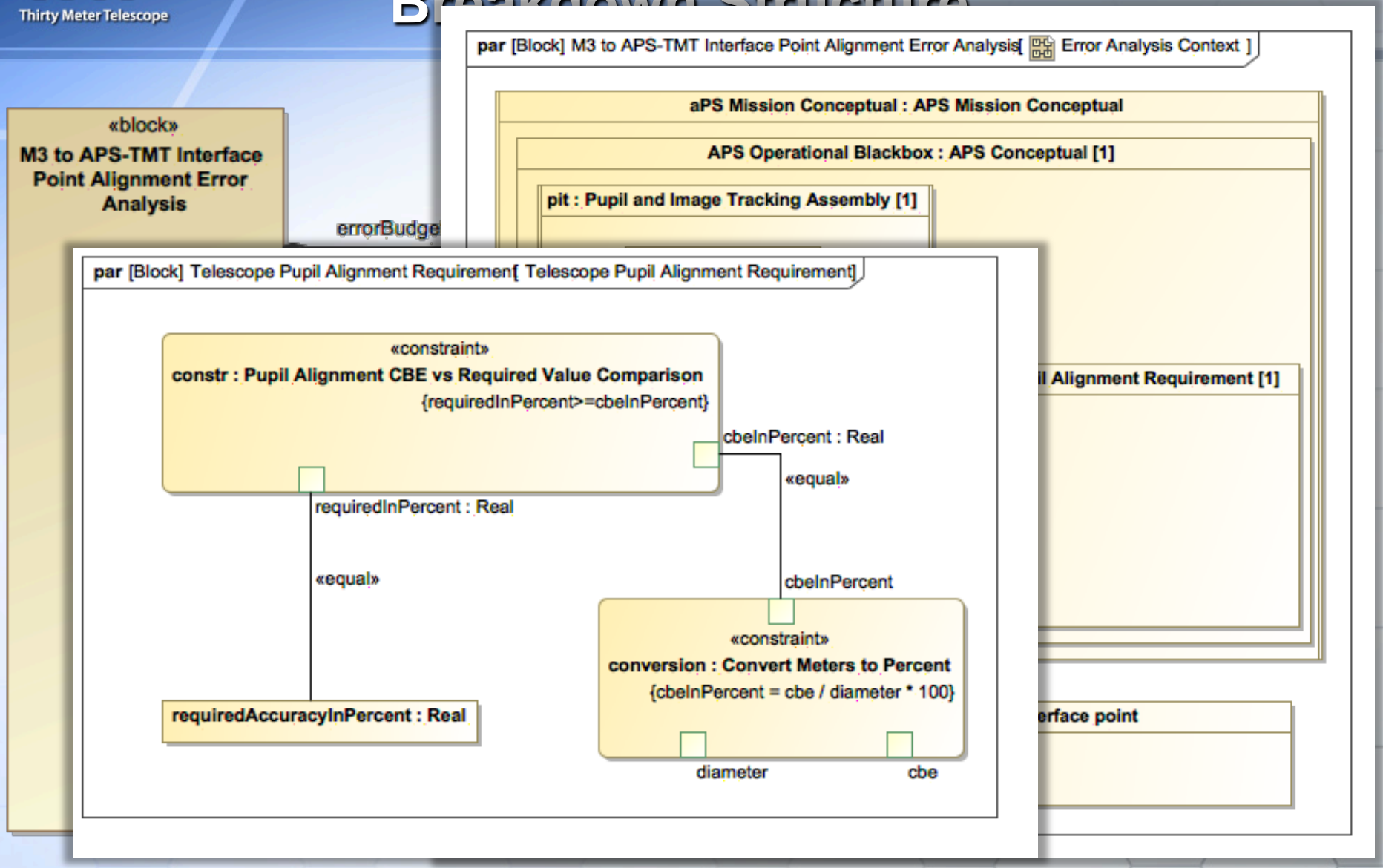


Pattern Application

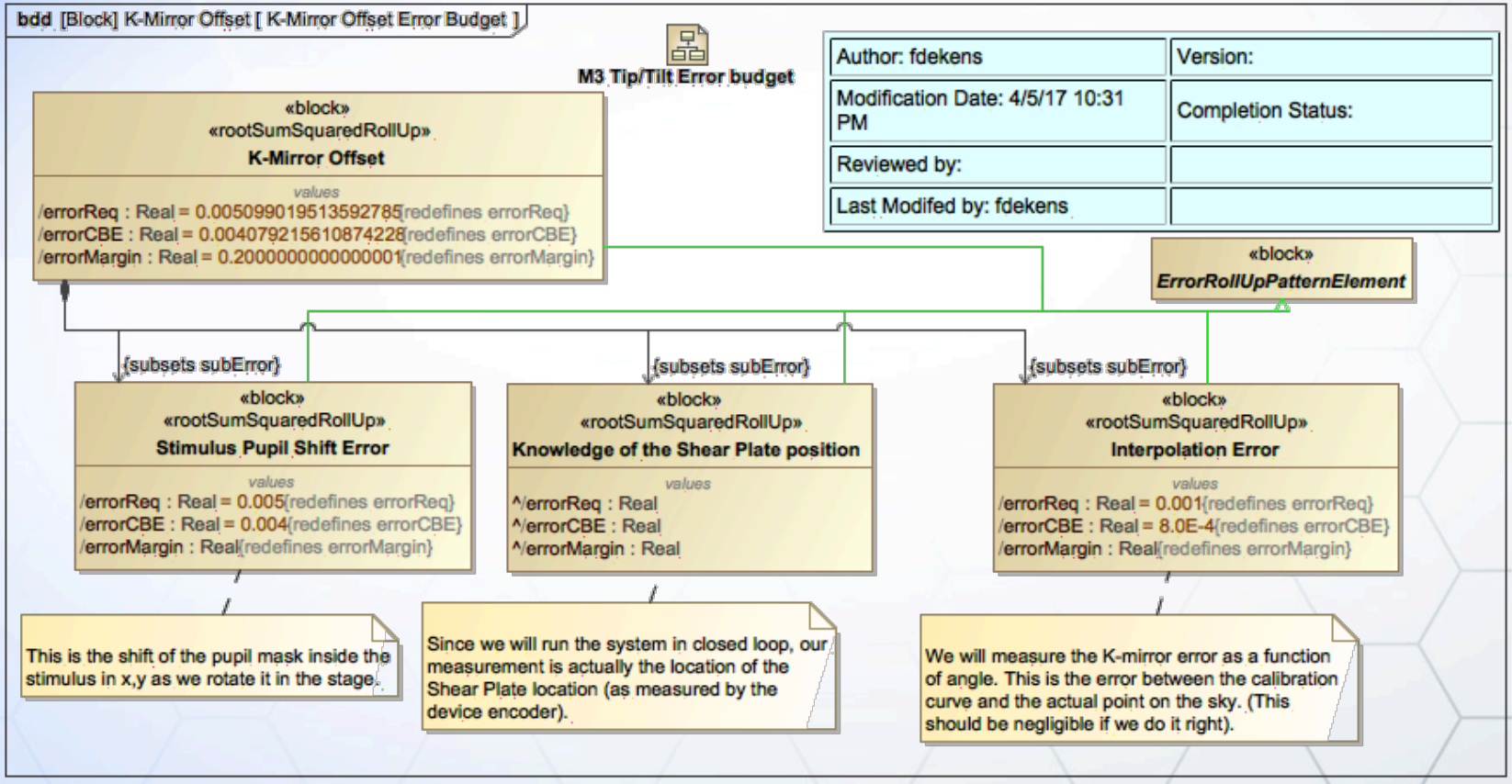


Tying to Requirements & Product Breakdown Structure



Solving & Results

- Parametric solver used for solving set of equations specified in model – here, *Cameo Simulation Toolkit* was used



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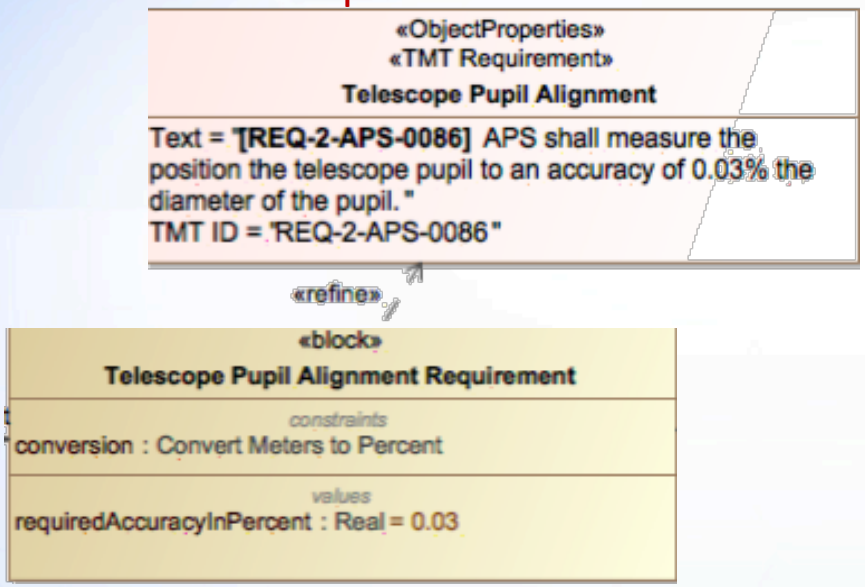
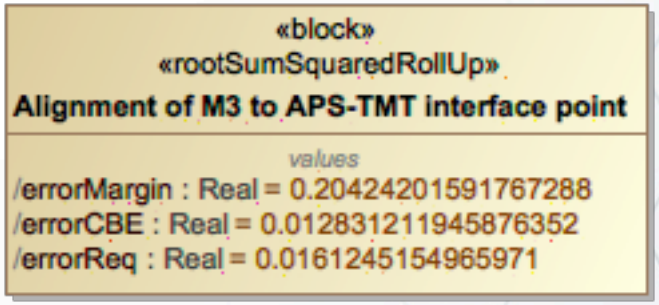
1. Formalized requirement



2. Automated roll-up

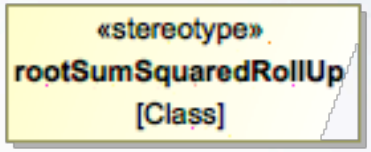


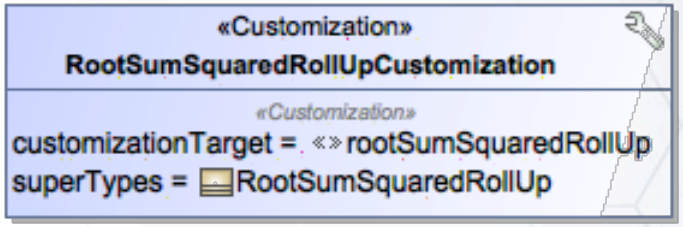
3. Automated verification of requirement

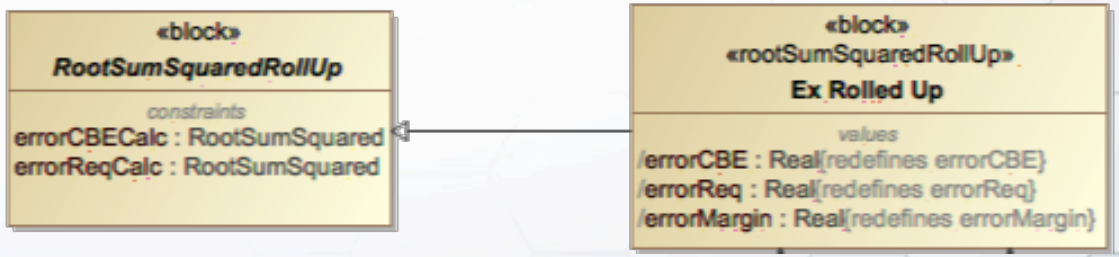
#	Name	Constr : Pupil Alignment CBE Vs Required Value Comparison
1	m3 to APS-TMT Interface Point	fail

MagicDraw Customizations

- If we hide inheritance, how do we know which type of error roll-up was applied?
- Also, inheritance cumbersome
- Used stereotypes and MagicDraw DSL customizations to solve both
- Automatic inheritance from a roll-up type when stereotype is applied
  - Unfortunately, no solution for subsetting…







How Does the Excel Method Compare to SysML?

- Typical Excel Error Budget
  - Pros:
    - Every one knows Excel!
    - Easy to make a copy for what-ifs
    - Easy to make changes
    - Easy to make yet an other error budget (copy one from an other project, or from online)
    - Extensive math libraries
    - Existing tools (queries, linking, etc.)
- Proposed SysML Error Budget
  - Pros:
    - Tied to requirements
    - Tied to system design
    - Tied or system parameters
    - Collaborative
    - Version controlled
    - Standardized through patterns
    - Can be extended to math languages (like Matlab, etc.)

Summary & Conclusions

- Demonstrated method and pattern for performing error budget analysis within a SysML model
  - Capture decomposition of error
  - Perform roll-up of current best estimates of leaf nodes
  - Calculate margins & verify requirements

- Method formally ties together requirements on accuracy, system design and relations between errors in an error budget
  - Safer → integration provides less danger of inconsistencies
  - Comes at a cost → careful modeling required

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References

- Open Source TMT model: https://github.com/Open-MBEE/TMT-SysML-Model
- A Practical Guide to SysML, 3rd Edition, Chapter 17 by Friedenthal, Moore, and Steiner

Backup