

SysML Parametrics Research for Modeling & Simulation Interoperability

- *DNA Signatures (Panorama plugin)*
- *STK/LVC Interoperability (AeroMagic plugin)*
- *Virtual Rover/STK (prototype)*

Development Team

- Selcuk Cimentalay (testing and feedback ideas)
- Russell Peak (objectives, requirements, and concepts)
- Andy Scott (Panorama & AeroMagic s/w development)
- Miyako Wilson (SysML parametrics s/w development)
- Collaboration with InterCAX and other vendors

Live/Virtual/Constructive Simulations (LVC)

Representative Toolset: STK (www.agi.com)



STKExpert

Products below included with STK Expert

Standard Modules

- Analyzer
- Integration
- Attitude
- Communications
- Coverage
- Radar
- TIM

STK
Professional

STK
Basic

Supplemental STK Modules

Modeling



Platforms

- Aircraft Mission Modeler
- Missile Modeling Tools
- Astrogator
- Attitude



Payloads

- Communications
- SATSOFT
- EOIR
- Radar



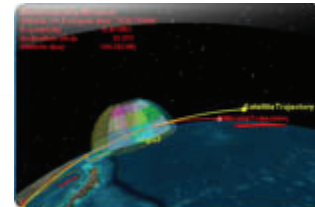
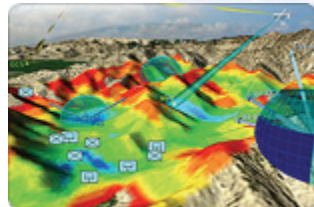
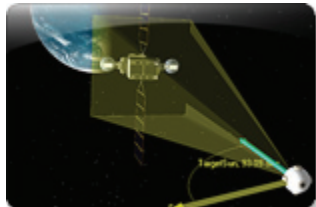
Environment

- Terrain, Imagery & Maps
- TIREM
- Urban Propagation
- GIS Analyst
- SEET
- RAE
- Weather Sentinel



Analysis

- Analyzer
- Optimizer
- Coverage
- CAT
- Scheduler

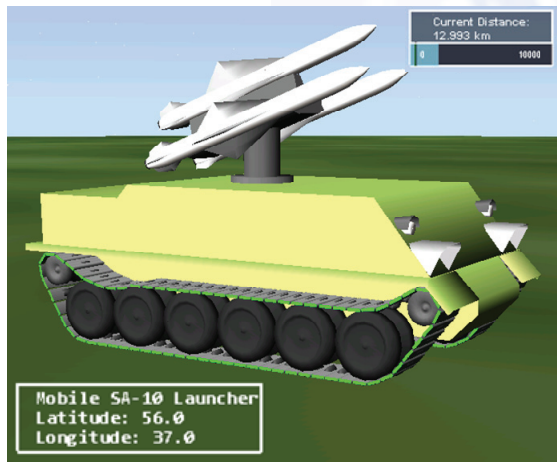


System/SoS M&S Examples in STK

Geo-positioning Model

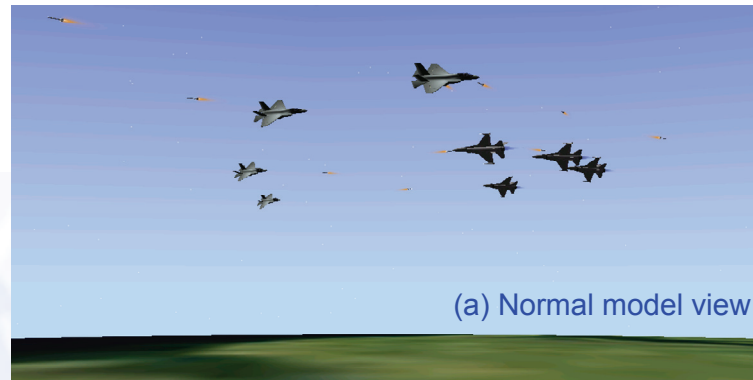


Missile Launcher Model

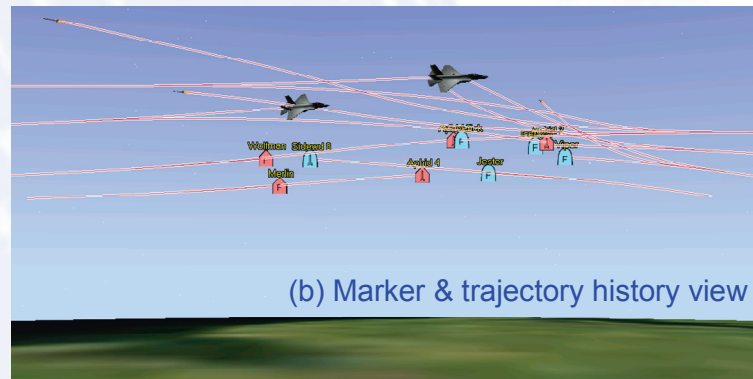


Based on original models by AGI.

Force-on-Force Fighter Simulation



(a) Normal model view



(b) Marker & trajectory history view

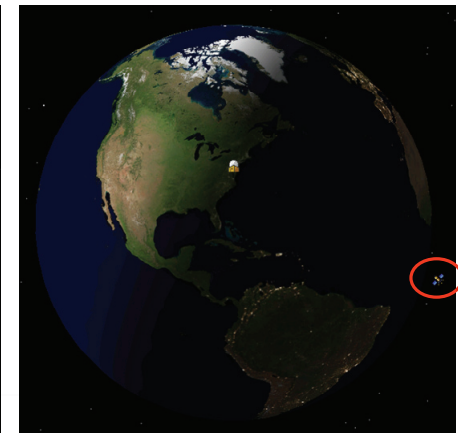
Communications Link Simulation between Satellite and Ground Station



(a) Link with ground station at $t=t1$



(b) Link with ground station at $t=t2$
(several orbits after $t1$)



(c) Link broken with ground station at $t=t3$
(~10 minutes after $t2$)

Two-way interoperability SysML-STK (throughout simulation run-time)

- Changeable inputs (SysML to STK): satellite and ground station properties
- ← Results (STK to SysML): duration of ea. link session with ea. ground station

bdd [Package] TestCases [twoLink_scenario1]

STK wrapper instances

```

«block»
twoLink_scenario1.0:TwoLink System Sim
sat_ArgumentOfPerigeeDeg = "300.2632"
sat_Bstar = "7.7165E-5"
sat_Classification = "U"
sat_Eccentricity = ".0008705"
sat_ElementNumber = "7594"
sat_Epoch = "09118.82643640"
sat_InclinationDeg = "51.64"
sat_InternationalDesignator = "98067A"
sat_MeanAnomalyDeg = "162.4789"
sat_MeanMotion = "15"
sat_MeanMotionDot = ".00009928"
sat_MeanMotionDotDot = "0"
sat_Name = "IcarusOrbitalMirror"
sat_RevolutionNumberAtEpoch = "98188"
sat_RightAscensionOfAscendingNodeDeg = "200.0022"
sat_SatelliteNumber = "0"
stationBlue_lat = "-33"
stationBlue_linkDuration_s = "0"
stationBlue_long = "122"
stationBlue_minElevationDeg = "0"
stationGreen_lat = "2"
stationGreen_linkDuration_s = "0"
stationGreen_long = "-76.0"
stationGreen_minElevationDeg = "0"

```

```

«block»
twoLink_scenario1.1:TwoLink System Sim
sat_ArgumentOfPerigeeDeg = "300.2632"
sat_Bstar = "7.7165E-5"
sat_Classification = "U"
sat_Eccentricity = ".8.705E-4"
sat_ElementNumber = "7594.0"
sat_Epoch = "9118.8264364"
sat_InclinationDeg = "0.0"
sat_InternationalDesignator = "98067A"
sat_MeanAnomalyDeg = "162.4789"
sat_MeanMotion = "15.0"
sat_MeanMotionDot = "9.928E-5"
sat_MeanMotionDotDot = "0.0"
sat_Name = "IcarusOrbitalMirror"
sat_RevolutionNumberAtEpoch = "98188.0"
sat_RightAscensionOfAscendingNodeDeg = "200.0022"
sat_SatelliteNumber = "0.0"
stationBlue_lat = "-20.0"
stationBlue_linkDuration_s = "1620.0", "1620.0", "1620.0",
"1620.0", "1620.0", "1620.0", "1620.0", "1620.0"
stationBlue_long = "122.0"
stationBlue_minElevationDeg = "-20.0"
stationGreen_lat = "2.0"
stationGreen_linkDuration_s = "1200.0", "1215.0",
"1215.0", "1215.0", "1215.0", "1200.0", "1200.0", "1200.0"
stationGreen_long = "-76.0"
stationGreen_minElevationDeg = "-10.0"

```

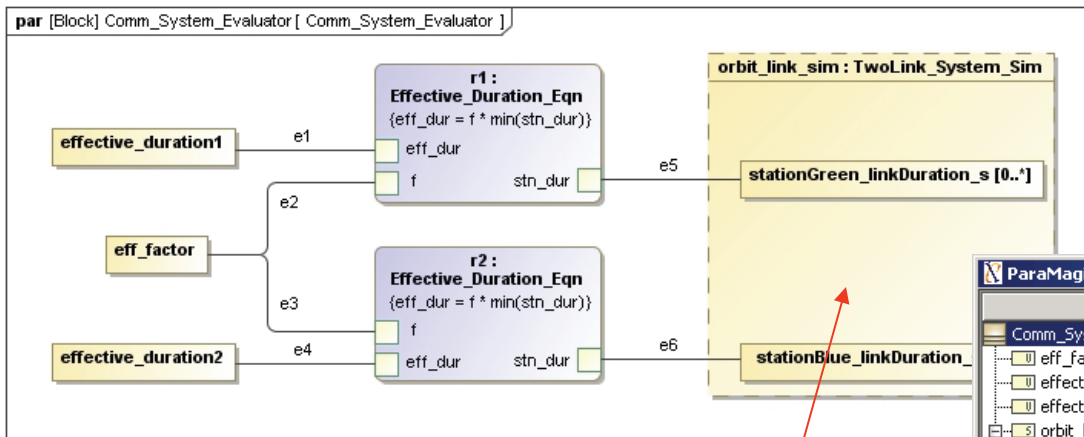
changes from scenario state 1.0 to 1.1

resulting range of expected values:
stationBlue_linkDuration_s: 1635.0 -> 1605.0
stationGreen_linkDuration_s: 1200.0 -> 1215.0
(at normal sim timestep/speed)

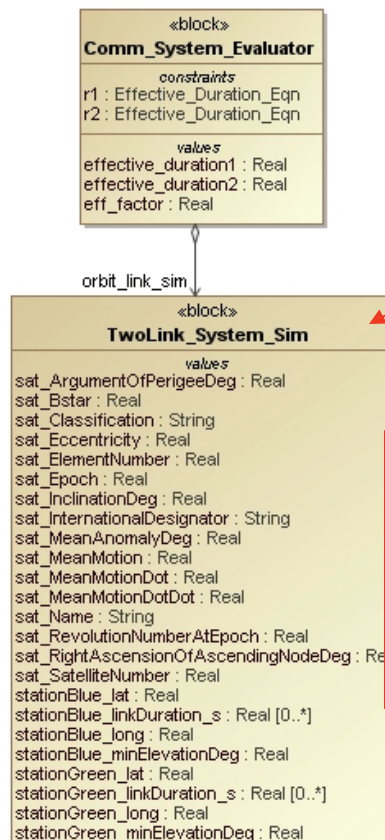
STK satellite comm. link sim (a constructive simulation)



Initial prototype: STK & SysML parametrics (for req. verification, ...)



bdd [Block] Comm_System_Evaluator [Comm_System_Evaluator]



STK wrapper block

Active connection between
SysML and LVC-type
simulations.

Impact: Can use SysML to
effectively V&V such sims.

ParaMagic(TM) 16.9 sp1 - cse1.1

Name	Type	Causality	Values
Comm_System_Evaluator	...	Comm_System_Evaluator	
eff_factor	REAL	given	0.500
effective_duration1	REAL	target	600.000
effective_duration2	REAL	target	810.000
orbit_link_sim	...	TwoLink_System_Sim	
sat_ArgumentOfPerigeeDeg	REAL	given	300.263
sat_Bstar	REAL	given	0.000
sat_Classification	STRING		U
sat_Eccentricity	REAL	given	0.001
sat_ElementNumber	REAL	given	7,594.000
sat_Epoch	REAL	given	9,118.826
sat_InclinationDeg	REAL	given	0.000
sat_InternationalDesignator	STRING		98067A
sat_MeanAnomalyDeg	REAL	given	162.479
sat_MeanMotion	REAL	given	15.000
sat_MeanMotionDot	REAL	given	0.000
sat_MeanMotionDotDot	REAL	given	0.000
sat_Name	STRING		IcarusOrbitalMirror
sat_RevolutionNumberAtEpoch	REAL	given	98,188.000
sat_RightAscensionOfAscendingNodeDeg	REAL	given	200.002
sat_SatelliteNumber	REAL	given	0.000
stationBlue_lat	REAL	given	-20.000
stationBlue_linkDuration_s	REAL[0,?]		
stationBlue_long	REAL	given	122.000
stationBlue_minElevationDeg	REAL	given	-20.000
stationGreen_lat	REAL	given	2.000
stationGreen_linkDuration_s	REAL[0,?]		
stationGreen_linkDuration_s[0]	REAL	given	1,200.000
stationGreen_linkDuration_s[1]	REAL	given	1,215.000
stationGreen_linkDuration_s[2]	REAL	given	1,215.000
stationGreen_linkDuration_s[3]	REAL	given	1,215.000
stationGreen_linkDuration_s[4]	REAL	given	1,215.000
stationGreen_linkDuration_s[5]	REAL	given	1,200.000
stationGreen_linkDuration_s[6]	REAL	given	1,200.000
stationGreen_linkDuration_s[7]	REAL	given	1,200.000
stationGreen_long	REAL	given	-76.000
stationGreen_minElevationDeg	REAL	given	-10.000

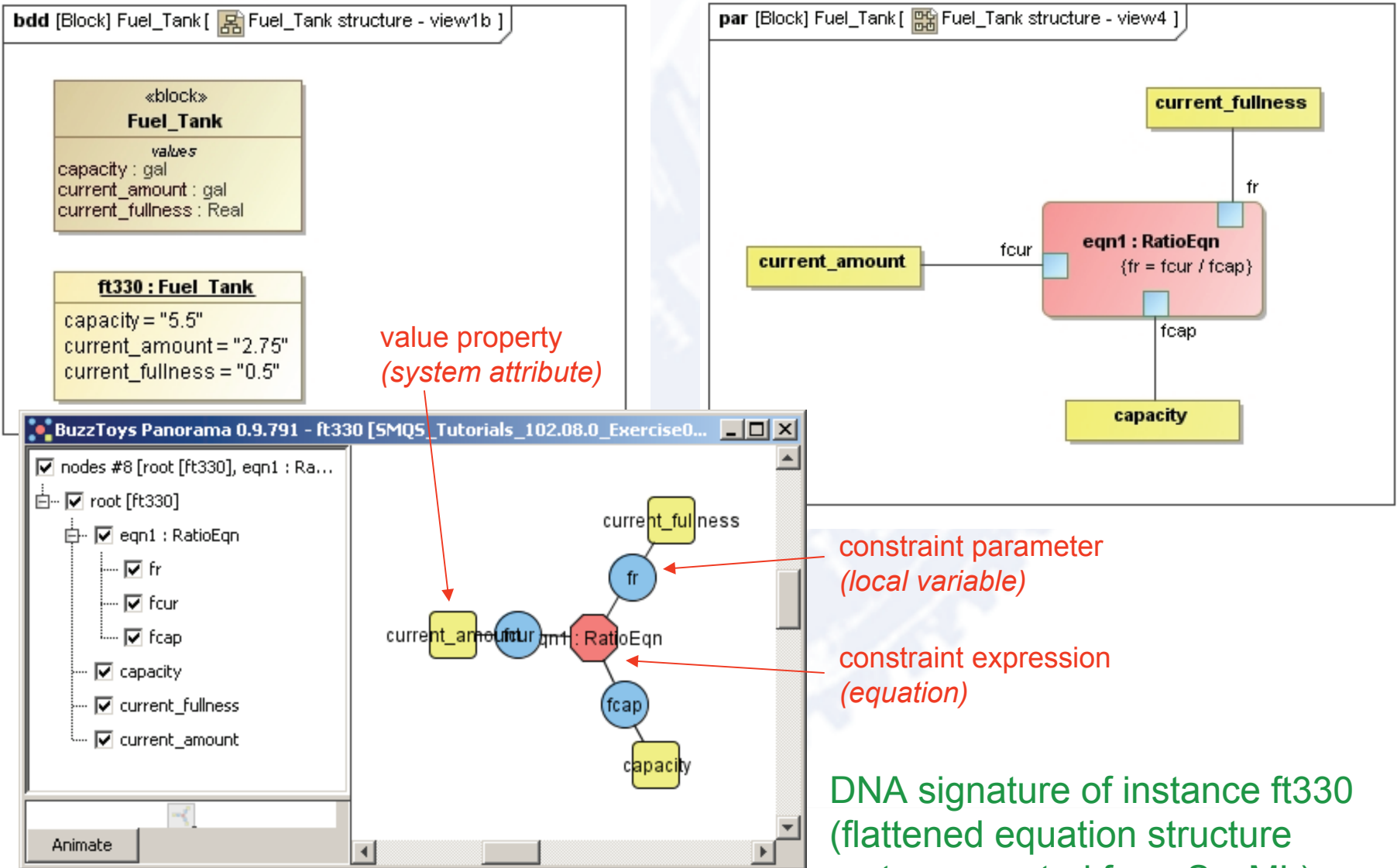
Expand Collapse All Solve Reset Update to SysML

root (Comm_System_Evaluator)

Name	Local	Oneway	Relation	Active
r1	Y	☑	effective_duration1=eff_factor*min(orbit_link_sim.stationGree...	☑
r2	Y	☑	effective_duration2=eff_factor*min(orbit_link_sim.stationBlue...	☑

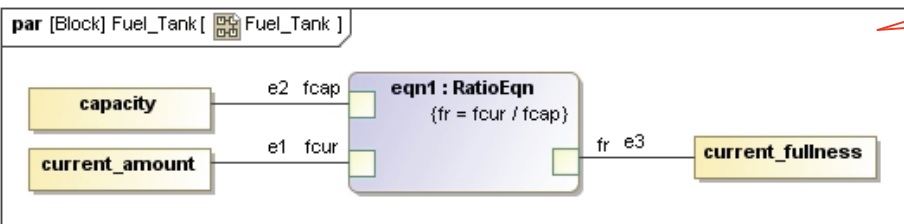
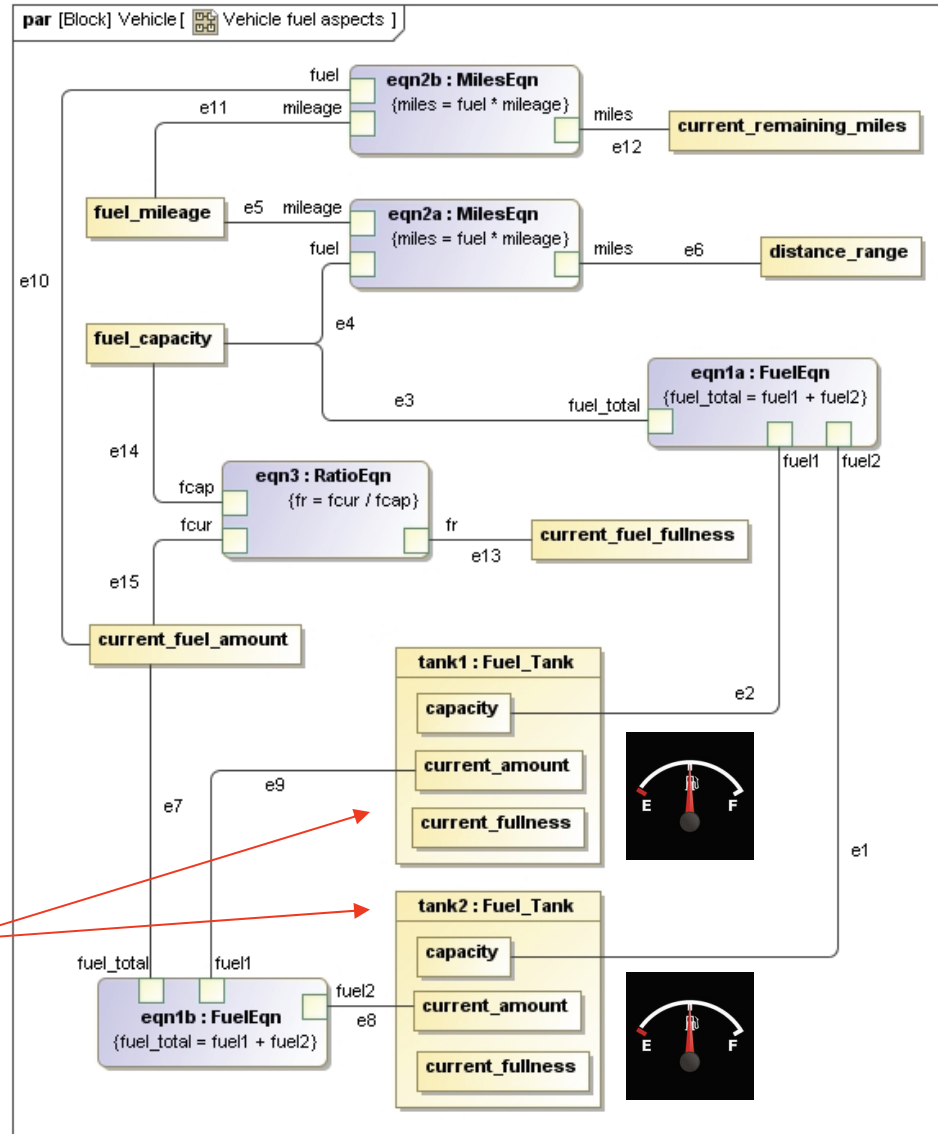
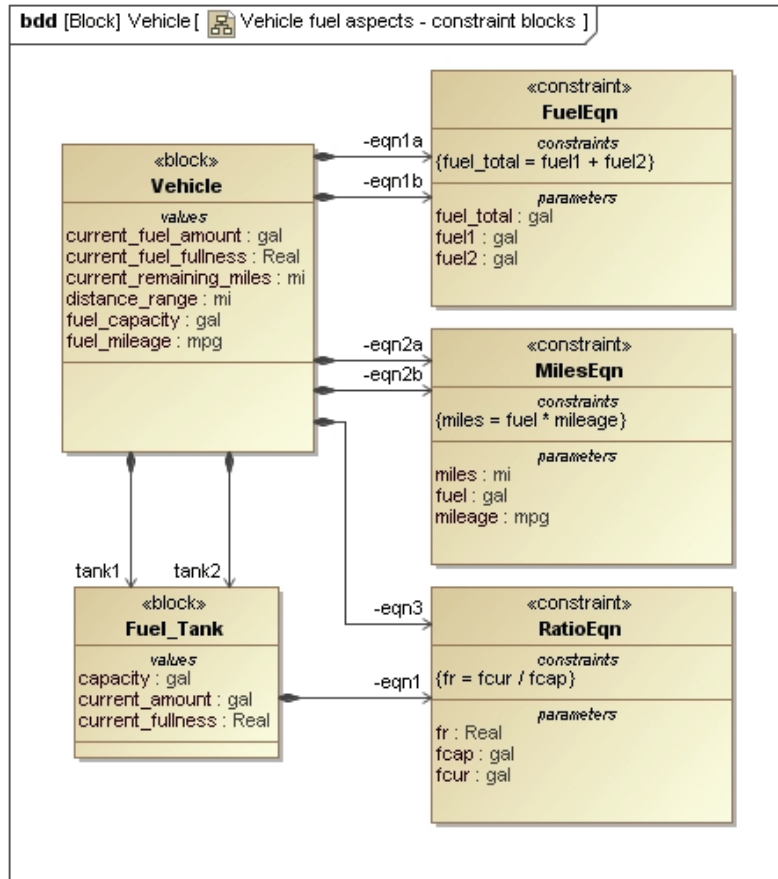
“DNA Signature” Nomenclature

Interacting with equation graph structure via Panorama tool



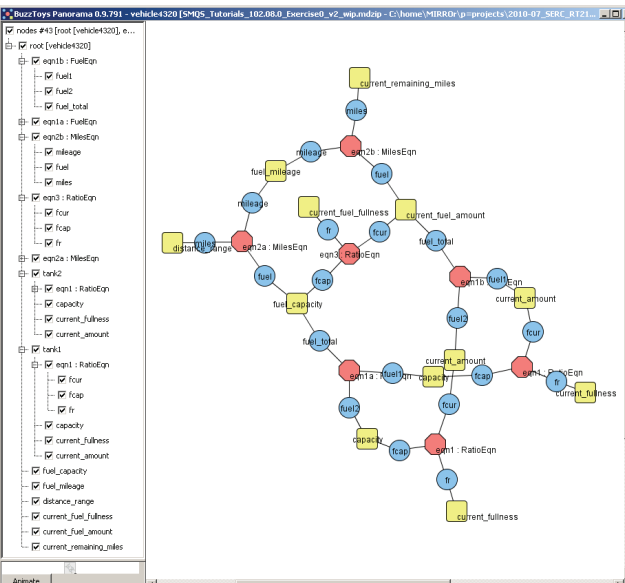
Exercise 0: Automobile Fuel Capacity & Mileage

Modular, Reusable Building Blocks



Exercise 0: Automobile Fuel Capacity & Mileage

Solved Instance and DNA Signature



ParaMagic(TM) 16.9 sp1 - vehicle4340

Name	Qualified Name	Type	Causality	Values
Vehicle	3_Target_Model_Stage3::vehicle4340::vehicle4340	Vehicle		
current_fuel_amount		REAL	ancillary	10.200
current_fuel_fullness		REAL	ancillary	0.650
current_remaining_miles		REAL	ancillary	428.400
distance_range		REAL	target	659.400
fuel_capacity		REAL	target	15.700
fuel_mileage		REAL	given	42.000
tank1	3_Target_Model_Stage3::vehicle4340::ft310	Fuel_Tank		
capacity		REAL	given	10.200
current_amount		REAL	given	10.200
current_fullness		REAL	ancillary	1.000
tank2	3_Target_Model_Stage3::vehicle4340::ft330	Fuel_Tank		
capacity		REAL	given	5.500
current_amount		REAL	given	0.000
current_fullness		REAL	ancillary	0.000

state 1.1 (after solving)

Expand Collapse All Solve Reset Update to SysML

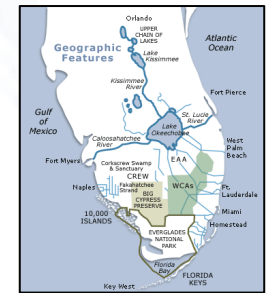
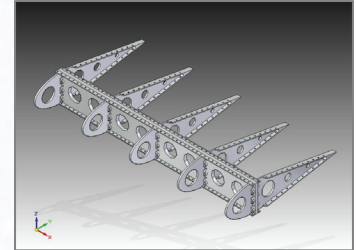
root (Vehicle)

Name	Local	Oneway	Relation	Active
eqn1a	Y	☐	fuel_capacity=tank1.capacity+tank2.capacity	☒
eqn1b	Y	☐	current_fuel_amount=tank1.current_amount+tank2.current_amount	☒
eqn2a	Y	☐	distance_range=fuel_capacity*fuel_mileage	☒
eqn2b	Y	☐	current_remaining_miles=current_fuel_amount*fuel_mileage	☒
eqn3	Y	☐	current_fuel_fullness=current_fuel_amount/fuel_capacity	☒

Broadly Applicable Technology

Examples of Executable SysML Parametrics

- Road scanning system using unmanned aerial vehicle (UAVs)
- UAV-based missile interceptor system trade study
- Space systems (tutorials): orbit planning; mass/cost roll-ups
- Space systems (studies/pilots): FireSat (INCOSE SSWG), ...
- Space systems (actuals): science merit function, ...
- Environmentally-conscious energy systems / smart grid
- Manufacturing “green-ness” / sustainability assessments
- Regional water management systems (e.g. South Florida)



- ...
- Mechanical part design and analysis (FEA)

...

- Wind turbine supply chain management
- Insurance claims processing and website capacity model
- Financial model for small businesses
- Banking service levels model

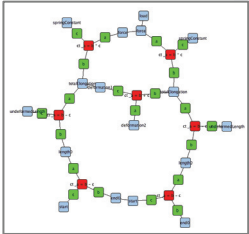
**Next-Generation
Spreadsheet Technology++**
(object-oriented, multi-dimensional, ...)



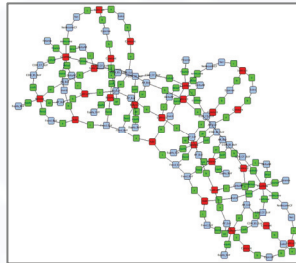
Model “DNA Signatures” Using SysML Parametrics

Examples as of ~9/2009 — Low/Medium Complexity

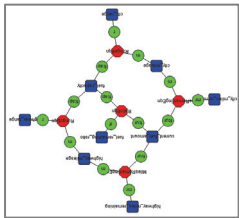
a. Snowman



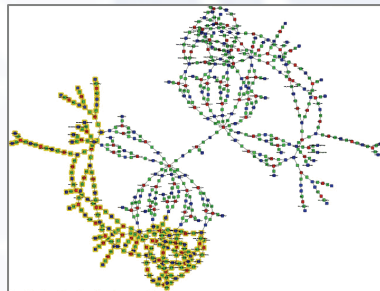
e. Cactus



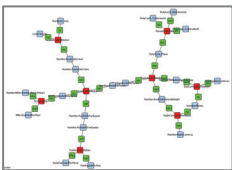
b. Mini Snowman



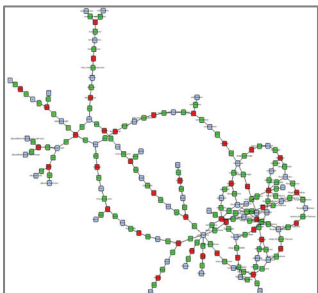
f. ?



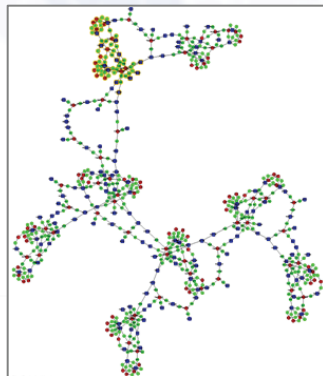
c. Snowflake



d. Mouse



g. Robot



Test: Match the actual model titles (below) to their “DNA signatures” with imagined titles (left).

- _____ 1. South Florida water mgt. (hydrology) model
- _____ 2. 2-spring physics model
- _____ 3. 3-year company financial model
- _____ 4. UAV road scanning system model
- _____ 5. Car gas mileage model
- _____ 6. Airframe mechanical part model
- _____ 7. Design verification model
(automated test for two Item 6. designs)

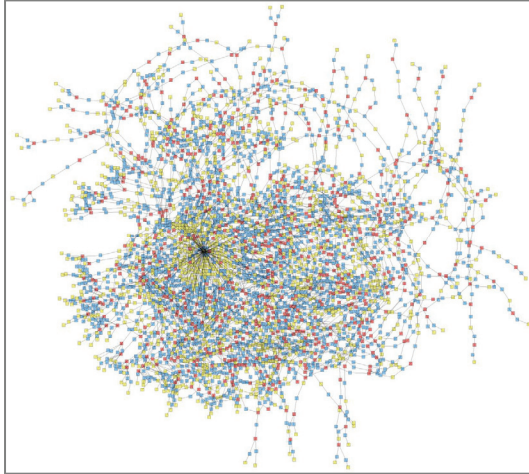
g. Springy Snowflakes

Recent Models: ~Medium Complexity

2010-10

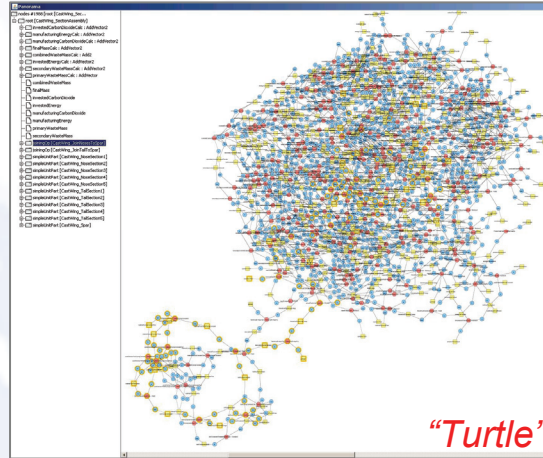
Model size = $O(100s)$ equations, $O(1000+)$ variables

supply chain metrics



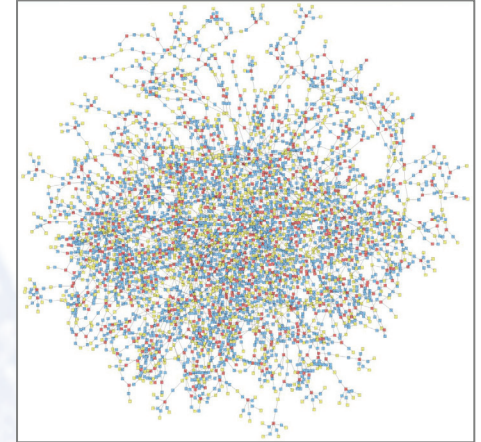
"Galaxy with Black Hole"

mfg. sustainability: airframe wing



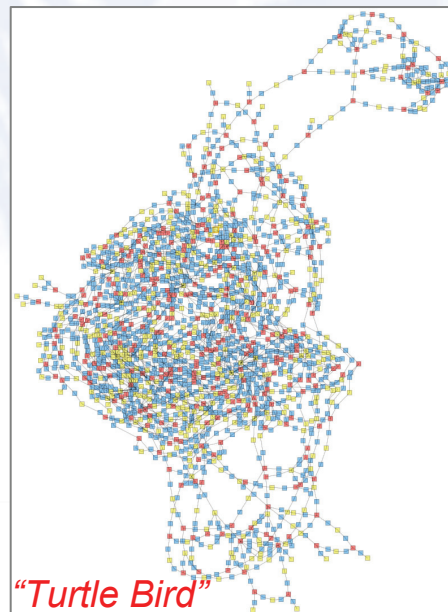
"Turtle"

electronics recycling network

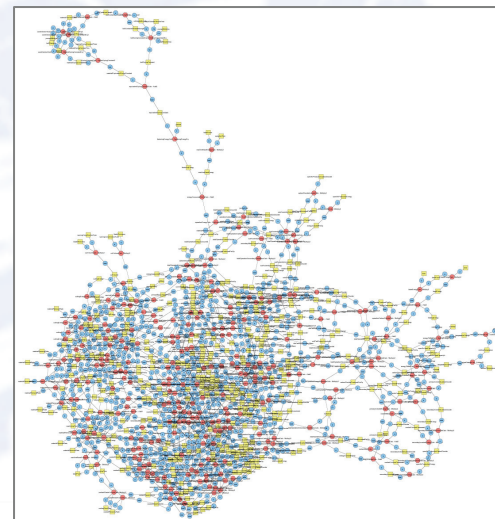


"Tumbleweed"

mfg. sustainability: automotive transmissions



"Turtle Bird"



"Angler Fish"

2010-12:

~20k variables

~15k equations

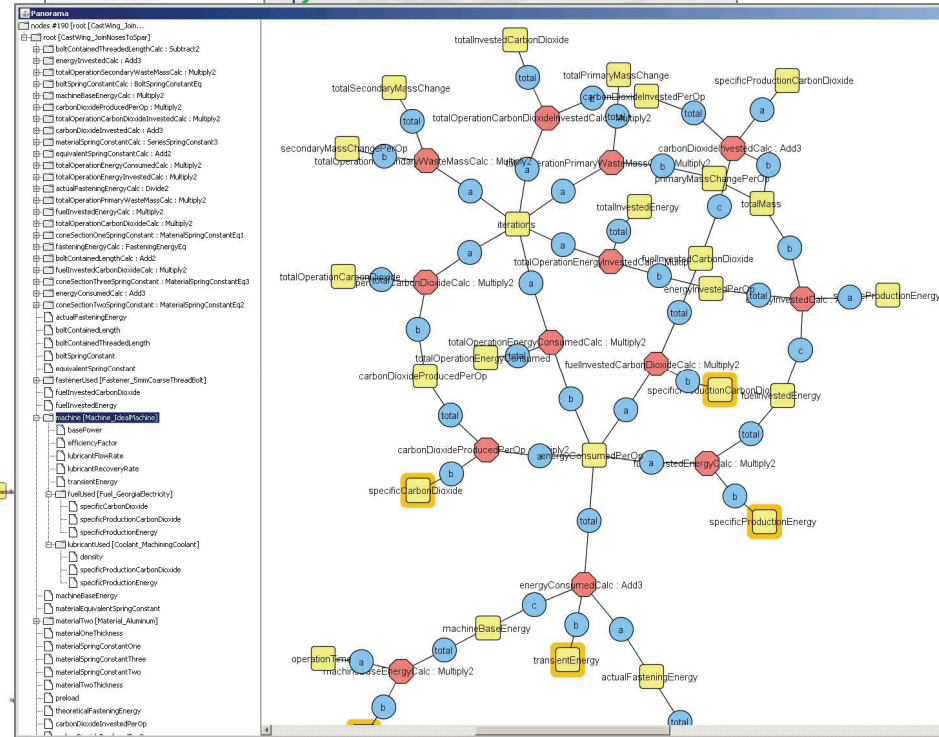
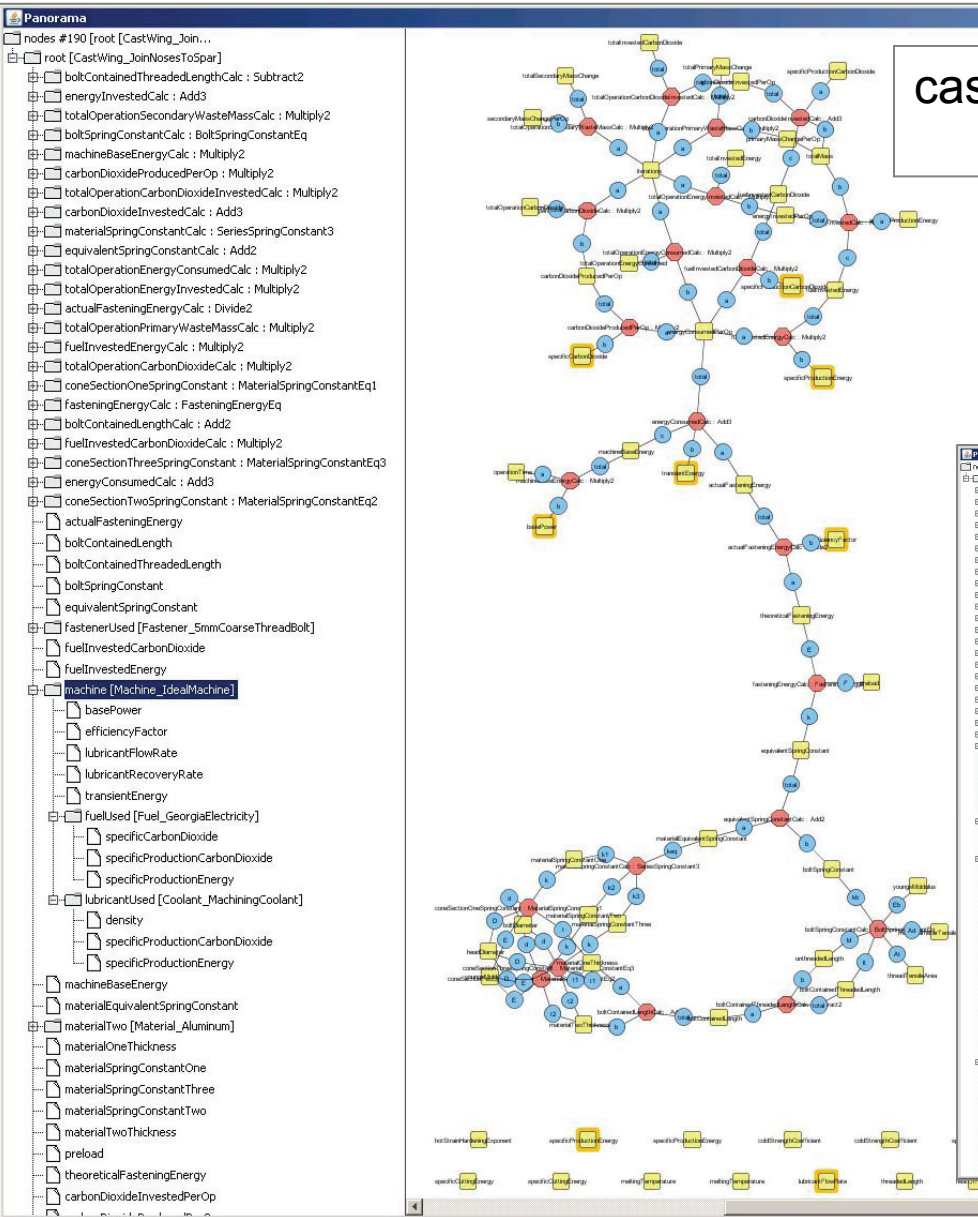
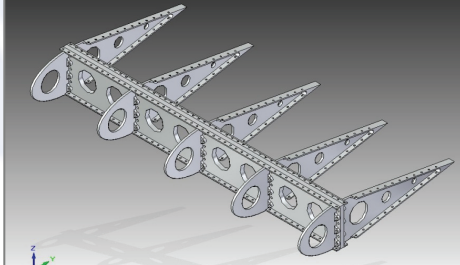
WIP:

100K, 1M, ...

Recent Models: ~Medium Complexity

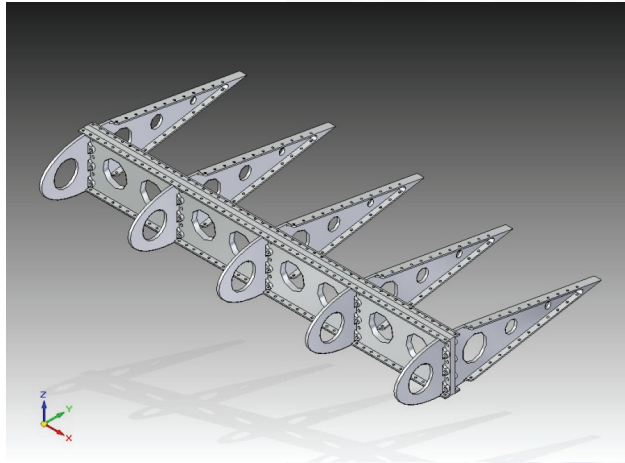
F-86 Cast Wing Assembly [adapted from Bras, Romaniw, et al.] – p2/3

cast wing – JoinNosesToSpar
(machine highlighted)



F-86 Wing Section Test Case in SysML Parametrics

Comparing Sustainability Metrics for Design Alternatives



ParaMagic(TM) 16.5 - Instance Library

"Object-Oriented Multi-Dimensional Spreadsheet++"

Name	Symbol	Type	Causality	Values
UnitPart		UnitPart		
forming		ListOfDieCastingOps		
materialRemoval		ListOfMaterialRem...		
sawing		ListOfSawingOps		
unitPartCarbonDioxide		REAL	target	34.825971386499
unitPartCarbonDioxideInvestment		REAL	ancillary	34.821506
unitPartEnergy		REAL	target	196,777,522.3729...
unitPartEnergyInvestment		REAL	ancillary	194,940,000
unitPartFinalMass		REAL	target	1.756994
unitPartOperationCarbonDioxide		REAL	ancillary	0.004465386499
unitPartOperationEnergy		REAL	ancillary	1,837,522.372948...
unitPartWasteMass		REAL	target	1.033006

Expand Collapse All Solve Reset Update to SysML

Value	Description	Change Aluminum to Steel
Total Carbon Dioxide	Total CO2 For Life of Part (up to this stage)	-25.3 kg
Total Energy	Total Energy for Life of Part (up to this stage)	-105.4 MJ = -29.3 kWh
Invested Carbon Dioxide	CO2 in Harvesting/Refining Raw Materials	-25.3 kg
Invested Energy	Energy in Harvesting/Refining Raw Materials	-110.4 MJ = -30.7 kWh
Operation Carbon Dioxide	Manufacturing/Fabrication CO2	+0.02 kg
Operation Energy	Manufacturing/Fabrication Energy	+502.2 kJ = +1.4 kWh
Final Mass	Final Part Mass	+3.4 kg
Waste Mass	Total Manufacturing Waste Mass	+0.1 kg

ParaMagic(TM) 16.5 - Instance Library

Name	Symbol	Type	Causality	Values
UnitPart		UnitPart		
forming		ListOfDieCastingOps		
materialRemoval		ListOfMaterialRem...		
sawing		ListOfSawingOps		
unitPartCarbonDioxide		REAL	target	9.49858067682
unitPartCarbonDioxideInvestment		REAL	ancillary	9.474244
unitPartEnergy		REAL	target	91,419,253.352
unitPartEnergyInvestment		REAL	ancillary	84,559,305.6
unitPartFinalMass		REAL	target	5.09674704
unitPartOperationCarbonDioxide		REAL	ancillary	0.02433667682
unitPartOperationEnergy		REAL	ancillary	6,859,947.751999...
unitPartWasteMass		REAL	target	1.12425296

Expand Collapse All Solve Reset Update to SysML

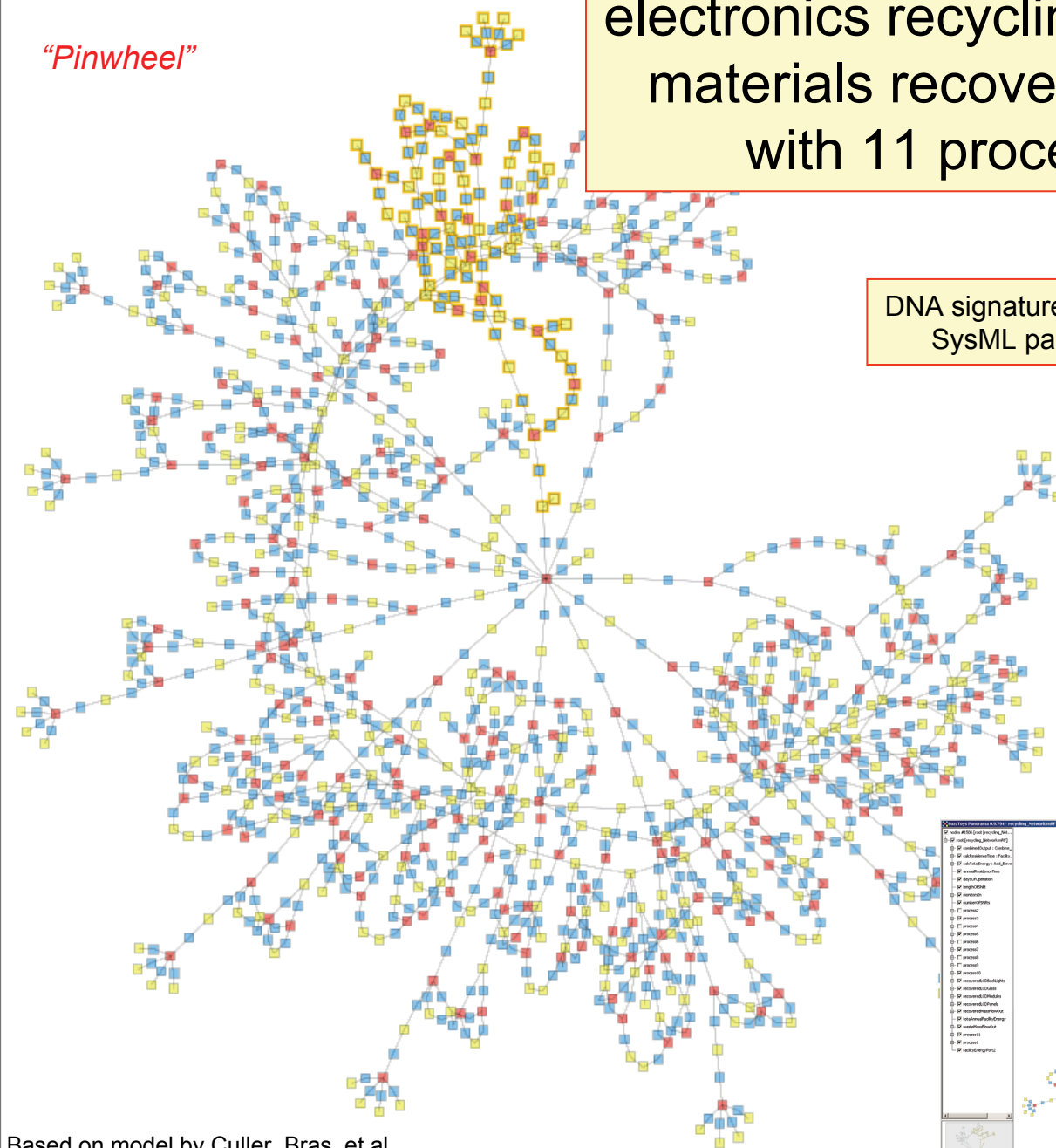
Source: Bras, Romaniw, et al. 10/2009
www.sdm.gatech.edu

electronics recycling network materials recovery facility with 11 processes

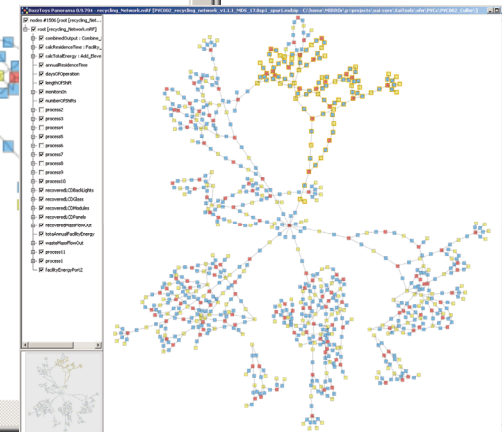
"Pinwheel"

DNA signature auto-generated from
SysML parametrics structure

user-controlled
model navigation
(on/off, pan, zoom)



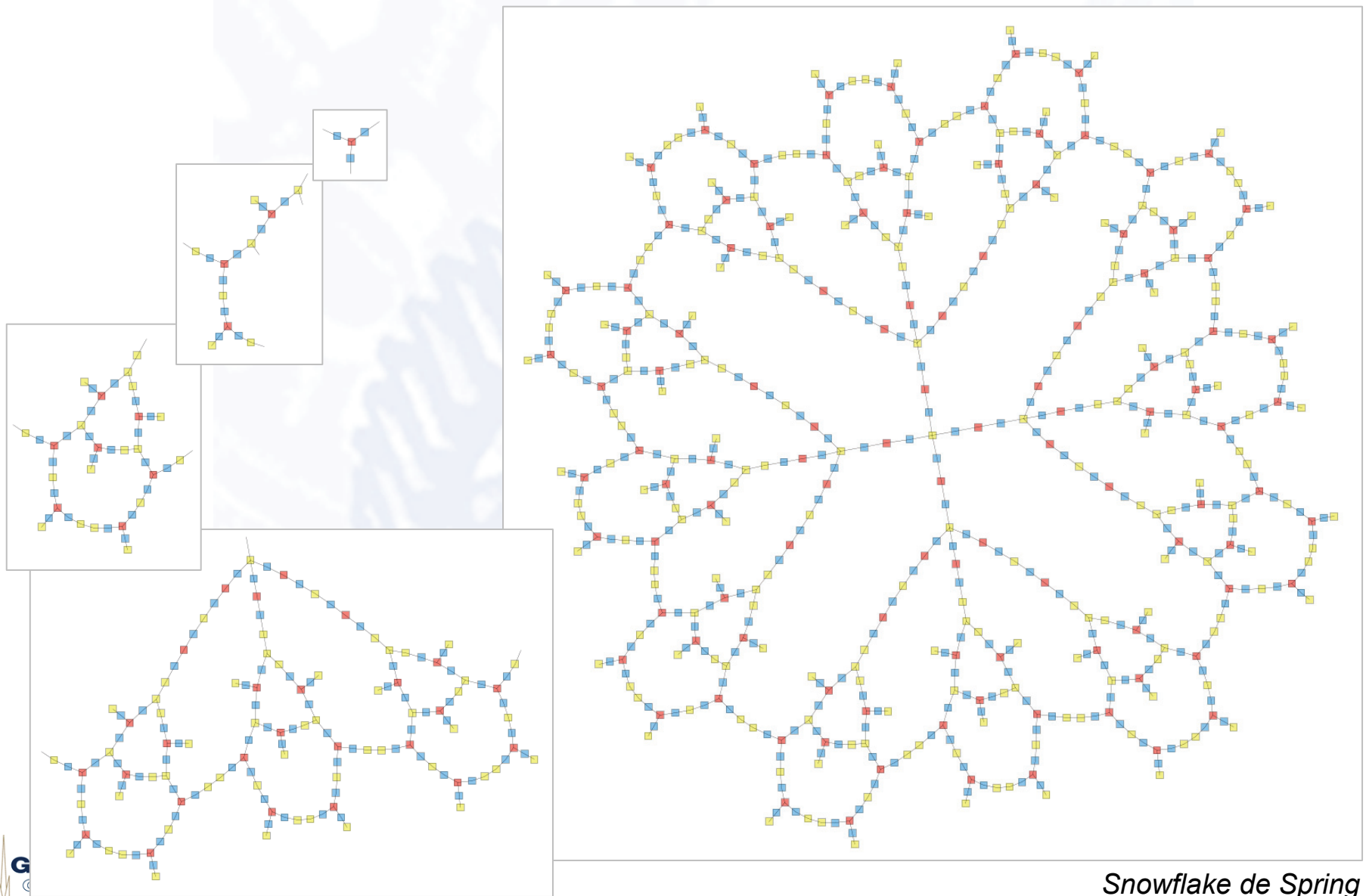
Based on model by Culler, Bras, et al.



Animate

Snowflake Composition

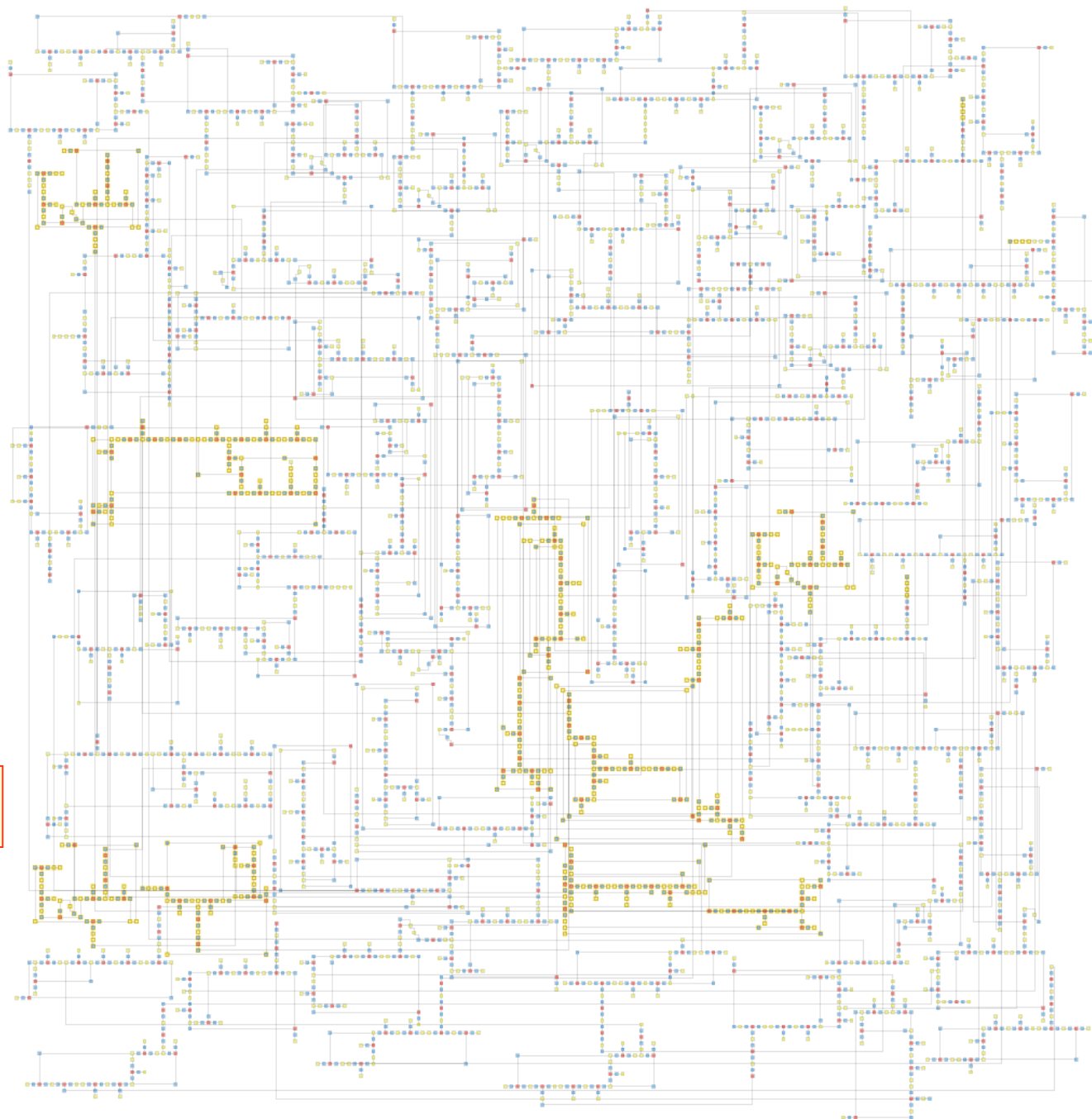
Five composition levels: primitive equation to system-of-systems



Snowflake de Spring



- ☒ nodes #4592 [root [qsb1], r12]
- ☒ root [qsb1]
- ☒ r12_1 : StartEqn
- ☒ r34_2 : StartEqn
- ☒ r012_1 : TriStartEqn
- ☒ r13_2 : StartEqn
- ☒ r24_2 : StartEqn
- ☒ r13_1 : StartEqn
- ☒ r34_1 : StartEqn
- ☒ r02a : StartEqn
- ☒ r012_2 : TriStartEqn
- ☒ r01a : StartEqn
- ☒ r12_2 : StartEqn
- ☒ r24_1 : StartEqn
- ☒ start0
- ☒ ssf_blob1
- ☒ ssf_blob2
- ☒ ssf_blob4
- ☒ ssf_blob3
- ☒ el2pd_con12
- ☒ el2pd_con41
- ☒ el2pd_con23
- ☒ el2pd_con34
- ☒ con01a
- ☒ con02a
- ☒ start_blob1
- ☒ start_blob2
- ☒ start_blob3
- ☒ start_blob4
- ☒ con01b
- ☒ con02b
- ☒ con012



alternative layout style
(and scalability testing)



Animate