Designing Systems & Software for Smart, Connected Systems

An MBSE Approach to IoT

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Agenda

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- PTC Vision of Smart Connected Systems
- Software/Systems Modeling (UML/SysML)
- Model transformation
- Product Line Engineering
- ThingWorx (IoT)
- Smart Connected System
- PTC ThingWorx Neuron
Standard Systems Engineering "V"

- Customer requirements, business initiatives / strategy, concept development
- Manufacturing / Service planning, execution; after-market activities

Plan
- Requirements Management
- System Architecture
- Software
- Electrical
- Mechanical

Develop

Test
- Validation
- Verification
Extended Systems Engineering “V”

Customer requirements, business initiatives / strategy, concept development

PTC Integrity™
Process Director™

Manufacturing / Service planning, execution; after-market activities

PTC Integrity™
Lifecycle Manager

PTC Integrity™
Modeler™

PTC® Windchill™

Requirements Management

System Architecture

Software

Electrical

Mechanical

Manufacturing

Service

Develop

Plan

Test

PTC® Creo®

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GPDIS_2015.ppt | 4
**PTC Integrity Modeler**

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### CAPABILITIES

- Scalable UML, SysML, UPDM
- Repository Collaboration
- Built-In Traceability
- Document Generation
- Automated Design Review
- System Simulation

### BENEFITS

- Improved Quality through Early Design Review and Consistency
- Bring Systems to Market Faster with Parallel Design Effort
- Cost Reductions from Design and Development Automation
PTC Integrity Modeler - Lifecycle Manager Integration

PTC Integrity Modeler

PTC Integrity Lifecycle Manager Synchronizer

PTC Integrity Lifecycle Manager

PTC Integrity

DOORS Adaptor

IBM Rational DOORS

PTC Integrity Connector

PTC Integrity

Requirements

Additional Model Elements

Model Trace Links

Requirements

Software baselines

PTC Windchill

PTC Integrity

Lifecycle Manager Integration

Requirements

PTC Integrity Modeler - Lifecycle Manager Integration

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GPDIS_2015.ppt | 6
1. Structure

```plaintext
<table>
<thead>
<tr>
<th>Library:</th>
<th>Electronic Processor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Library:</td>
<td>Electro-Hydraulic Valve</td>
</tr>
<tr>
<td>Block:</td>
<td>Anti-Lock Controller</td>
</tr>
<tr>
<td>Block:</td>
<td>Traction Detector</td>
</tr>
<tr>
<td>Block:</td>
<td>Brake Modulator</td>
</tr>
</tbody>
</table>
```

2. Behavior

```plaintext
<table>
<thead>
<tr>
<th>Activity:</th>
<th>PreventLockup</th>
</tr>
</thead>
<tbody>
<tr>
<td>State Machine:</td>
<td>Gripping, Slipping</td>
</tr>
<tr>
<td>Function:</td>
<td>Detect Loss Of Traction</td>
</tr>
<tr>
<td>Function:</td>
<td>Modulate Braking Force</td>
</tr>
</tbody>
</table>
```

3. Requirements

```plaintext
| Requirement: | Stopping Distance |
| Requirement: | Anti-Lock Performance |

Vehicle System Specification

- id: 102
- txt: The vehicle shall stop from 60 mph within 150ft on a clean dry surface.

Braking Subsystem Specification

- id: 317
- txt: The Braking subsystem shall prevent wheel lockup under all braking conditions.

```
Why use modeling tools?

Support the automatic generation of “things” from the model

ACS/TKD offers combination of:
- Speed
- Flexibility (to define the mapping)

ACS

TKD

Model-based transformations

Edit/compile code in IDE

Model Driven

GENERATE

FORWARD

CHANGE

ROUNDTRIP

CODE

GENERATE

FORWARD

ROUNDTRIP

Model

Cache

Context

Modeler

Transformation Model

Ada
Java
C/C++
C#
Visual Basic
IDL/IDL3+
Code Generation Customization (Transformation Model)

**QClass**

**Rules**
- Gen -> "Class" . Name "{" CR +1 dConstructorGen CR dDestructorGen CR ClassBody -1 "};" CR CR;
- ClassBody -> [Attribute.Gen] [Operation.Gen];
- implGen -> "/" TESTING ONLY;
- dConstructorGen -> "void" . Name "()" [" CR +1 dConstBodyGen -1 CR "];
- dDestructorGen -> "void" . Name "()" [" CR +1 dDestBodyGen -1 CR "];
- dConstBodyGen -> "stuff iam here;";
- dDestBodyGen -> "/" don't allow destruction" CR +1 "hi";

When (in O : %object) : %numeric

**QInterface**

**Rules**
- Gen -> "Interface" . Name "+" CR +1 dConstructorGen CR dDestructorGen CR ClassBody -1 ");" CR CR;

When (in O : %object) : %numeric

**QAttribute**

**Rules**
- Gen -> Access":" . Data Type _ Name ["=" Default Value "] ";" CR;

When (in O : %object) : %numeric

**QFakeOperation**

**Rules**
- Gen -> Short Return Type _ Name "(" [Parameter.Gen "," Parameter.Gen] ")" CR;

When (in O : %object) : %numeric

**4GGenerator::4GStructure::Class**

Name : %string
Visibility : %string

**4GGenerator::4GStructure::Attribute**

Data Type : %string
Name : %string
Default Value : %string
Access : %string

**4GGenerator::4GStructure::Operation**

Name : %string
Short Return Type : %string
Access : %string
Text : %string
Data Mining/Data Analysis (ICD Generator)

VBA/VB scripting engine inside Modeler

- Generate traditional Systems documentation from modeling information
Asset-Based Modular Design

• Design the same way you Build
  – Construct Systems of Sub-Systems (SoS)
  – Use Services to build your Application (SOA)
  – Plug Components together (CBD)

• Modular Design
  – Top-Down, Architected
    – Specification (& Requirements) Driven
    – Parallel Working
    – Separation of Concerns
  – Bottom-Up, Asset Mining
    – Un-modeled Assets
    – Other Modeling Tools
    – Legacy Integration
    – Published Interfaces (e.g. IDL)
Asset-Based Modular Design

- Publish from Sub-system model into PTC Integrity Asset Library
  - Auto-creates Trace Links
System Product Line Engineering (PLE) Challenges

Product line explosion
- Increasing number of product families
- Increasing number of products in families
- Understanding product similarity
- Maximizing reuse
- Understanding product variations
- Deciding between options
- Development cycle time
- Commercial product needs
  - Customize existing capabilities to suit client requirements
  - Redeploy common systems & software to the Market
  - Time from requirements to cash

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Designing a single system platform rather than as creating a multitude of products

**MBSE + Modular Design + Variation**
- Common language improves
  - Communication
  - Collaboration
  - Stakeholder buy in
- Architected modular design & reuse
- System product lines designed up front

**Maximum commonality & minimal variation**
- Less duplicated effort with optimized reuse
- Parallel working through ‘design by contract’
- More commonality between designs and implementations
- Managed product line complexity

**OVM Standards Based**
- PALUNO, The Ruhr Institute of Software Technology
- Software Product Line Engineering (Pohl et al - Springer 2005)
Modeling Product Lines
Modeling Variability

- Engine variability along with model dependencies

![Diagram showing variability points and models](var_04 Engine Variant Diagram)

Variation Points
Alternative Choices
Variants
Modeling elements

- Diesel Engine
- Gasoline Engine
- Efficient
- Fast
# Decision Set Editor Variant Selector Examples

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<table>
<thead>
<tr>
<th>Name</th>
<th>Decision</th>
<th>Status</th>
<th>Included By</th>
<th>Excluded By</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic</td>
<td></td>
<td></td>
<td></td>
<td>Excluded</td>
<td></td>
</tr>
<tr>
<td>Luxus</td>
<td></td>
<td></td>
<td></td>
<td>Excluded</td>
<td></td>
</tr>
<tr>
<td>Keyless Entry Option</td>
<td></td>
<td></td>
<td></td>
<td>Excluded</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td>Included</td>
<td></td>
</tr>
<tr>
<td>Line</td>
<td>Line</td>
<td>Included</td>
<td>Variable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td></td>
<td>Include</td>
<td>Included</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic</td>
<td></td>
<td></td>
<td></td>
<td>Excluded</td>
<td></td>
</tr>
<tr>
<td>Luxus</td>
<td></td>
<td></td>
<td></td>
<td>Excluded</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Multimedia Supplier</td>
<td>Included</td>
<td>Variable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The well-known, expensive Brand</td>
<td></td>
<td></td>
<td>Excluded</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The cheaper, better, but quite unknown Brand</td>
<td></td>
<td>Include</td>
<td>Included</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Battery Size</td>
<td>Included</td>
<td>Variable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>65Ah</td>
<td></td>
<td></td>
<td></td>
<td>Excluded</td>
<td></td>
</tr>
<tr>
<td>44Ah</td>
<td></td>
<td></td>
<td></td>
<td>Included</td>
<td></td>
</tr>
</tbody>
</table>

- **Variants:** 15/5  
- **Variation Points:** 8/21  
- **Inconsistent:** 0  
- **Undecided Mandatory Variation Points:** 9

---

**Example Model for Atego Perspective, Version 4**

- **Car Types:** for the city  
- **Motor Type:**  
- **Air Conditioning:**  
- **Route Directives:**  
- **Car Colour:**  
- **Connectivity:**  
- **USB:**  
- **Bluetooth version:**  
- **Data Input:** keyboard  
- **Screenlock:**  
- **External and Optional:**  
- **External and Mandatory:**  
- **Routing Options:** Voice  
- **Comfort Options:** Keyless Entry  
- **Line:** Base  
  - **Reason:** There are three main car equipment lines, from which one is to be chosen: 1. Base for the price-sensitive customer 2. Dynamic for the more sporty customer 3. Luxus for the customer who wants to equip the car with all the luxury possible.
PTC Integrity Modeler SySim

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**CAPABILITIES**

- Early Complex Behavior Validation
- Block Level Reuse
- Drop-&-Play Simulation
- Connect to External Simulators
  - MATLAB Simulink™, etc.

**BENEFITS**

- Typical 20% reduction in model ‘Design Walkthrough’ effort
- Up to 30% reduction in design errors
- Significant reduction in overall project costs
New Reality: Distinct but Inseparable

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INTERNET OF THINGS

Digital World

Real World
PTC’s Enterprise IoT Vision

Produce and manage Smart, Connected Products

Digital Twin

Leverage Smart, Connected Product data to improve products
With Augmented Reality (Software Configuration)
With Augmented Reality (Software Configuration)

User toggles between hardware, fluid, electrical and software views of the product.

Relevant details about the software configuration are obtained from the product and the cloud.

Alerts are presented in the context of the system or subsystem.

Drill down into a number of connected Apps to get details on specific content.

Johnny Hockey

Warning 002334: Software recall on ECU3445.

Update

SEN9933 – firmware v7.2.33.2
SEN7430 – firmware v4.54.3.221
ECU3445 – firmware v1.23.54.506
DRV1011 – v0.9.89.322

SEN7430 – infinite loop logging war...
SEN7293 – memory not released when...

Details
Model Data Mining (ICD)
Model Analysis (SWAP-C)
Simulation Analysis (SySim)
IoT Visualization (ThingWorx)
Simulate and Publish Data for IoT Subscribe
Predictive Signals

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NeuronDiscover

Category View

- Time and Location
- Soil Temperature
- Weather Solar Radiation
- Weather Potential Evapotranspiration
- Weather Air Temperature
- Weather Apparent Temperature
- Weather Wind Chill
- Weather Wind Chill AVG 0 to 1 DAY prior
- Weather Wet Bulb Temperature
- Weather Diffuse Radiation
- Weather Direct Radiation
- Weather Air Pressure

Profiles

- Weather Diffuse Radiation AVG 4 to 5 DAY prior: [17.26 - 36.71], Avg. 33.66, Population 10,061, Z Score 33.17
- Weather Relative Humidity AVG 8 to 9 DAY prior: [8.75 - 62.76], Avg. 31.78, Population 6,170, Z Score 35.32
- Weather Relative Humidity AVG 10 to 11 DAY prior: [8.75 - 73.56], Avg. 31.22, Population 5,405, Z Score 35.49
- Weather Wind Direction AVG 0 to 1 DAY prior: [115.37 - 235.3], Avg. 30.17, Population 4,365, Z Score 36.23

Choose Prediction: Soil Moisture 16in (weather only)
Choose Filter: All Data
Predictive Analyzer

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NeuronDiscover

PREDICTED PERFORMANCE

Soil Moisture Prediction Next Week @ 16in

ESTIMATED MODEL ACCURACY

94.37%

RMSE 0.06
PEARSON CORRELATION 0.98
VALIDATION RECORDS 14827

FACTORs INFLUENCING PREDICTION FOR +1 DAY

<table>
<thead>
<tr>
<th>Feature Name</th>
<th>Feature Value</th>
<th>Influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location Name</td>
<td>Location 5</td>
<td></td>
</tr>
<tr>
<td>Weather Wind Chill AVG 0 to 1 DAY prior</td>
<td>69.5</td>
<td></td>
</tr>
<tr>
<td>Weather Apparent Temperature AVG 0 to 1 DAY prior</td>
<td>69.58</td>
<td></td>
</tr>
<tr>
<td>Weather Air Temperature AVG 0 to 1 DAY prior</td>
<td>69.5</td>
<td></td>
</tr>
<tr>
<td>timestamp_month_of_year</td>
<td>4 April</td>
<td></td>
</tr>
</tbody>
</table>

ENSEMBLE METHODS

<table>
<thead>
<tr>
<th>Enabled</th>
<th>Learning Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BACKPROP</td>
</tr>
<tr>
<td></td>
<td>DECISION TREE</td>
</tr>
<tr>
<td></td>
<td>LINEAR REGRESSION</td>
</tr>
<tr>
<td></td>
<td>GRADIENT BOOST</td>
</tr>
</tbody>
</table>
Questions and Answers

Thanks for your attention!