Institute for Software-Integrated Systems

Technical Report

TR#: ISIS-15-114

Title: Transitioning the META Toolchain

Authors: Ted Bapty, Sandeep Neema and Jason Scott

This research is supported by the Defense Advanced Research Project Agency (DARPA)'s AVM META program under award #HR0011-13-C-0041.

Table of Contents

ISIS
Tel (615) 343-7472 Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu
VANDERBILT UNIVERSITY

List of Figures

1. Introduction

The comprehensiveness of the OpenMETA tool functionality - spanning a significantly large gamut of Cyber-Physical Systems (CPS) design spectrum, and the relative maturity of the produced toolset has generated significant interest and demand for transition. Several activities are either ongoing or planned. We describe these activities below in the Commercial, Defense, and Academic areas.

2. Commercial Transitions

In September 2013, Metamorph Inc. was created for the purpose of transitioning open-source, research-derived software and processes. This company has received significant interest, and is pursuing several high profile application domains and markets for the OpenMETA tools.

2.1. Google Project Ara

Google Project Ara, http://en.wikipedia.org/wiki/Project_Ara, is an initiative to develop a modular phone. The core phone is simply a mechanical backplane with an integrated high-speed data bus, and a power distribution network. All functionality of a customized phone is derived from the modules installed by the user from display, core processing units, antennas, to special purpose, market-specific modules, such as cameras, bio sensors, physical measurements, special purpose radios, along with the creative ideas from the marketplace (see Figure 1). This expansion capability promises to add an entire hardware market space to the typical smartphone "App" space.

Figure 1: Module Examples

For the modularization capability to have an impact and succeed, the market must create modules, in a similar way that the variety of Apps contributed to the success of the smartphone. Encouraging and enabling the development of Apps, the Android Development Kit is freely available for the creation of software. A similar capability is required for hardware.

The Ara hardware module is effectively a cyber-physical system, with multiple domains of concern. Conformance specifications and minimal requirements are specified in the project Ara Module Developers Kit, available at http://www.projectara.com/mdk/. The MDK, along with the basic necessities of achieving functionality and performance, result in a large set of tool needs:

- Analog circuit analysis for simulation of circuit functionality and bandwidth.
- Analysis of noise from cross coupling and transmission line effects.
- Digital circuit functionality and timing.
- Software functionality and timing, across multiple subsystems.
- Thermal behavior, including constraints on thermal dissipation to the phone case.
- Power constraints, limits on the amount of power available per module slot.
- Radio Frequency (RF) behavior: Power and directivity of an assembled module in all legal points of the phone.

Manufacturing in the Metamorphosys tools is also a major capability extension, relative to the AVM iFAB capability:

- Real-time cost and availability of parts, with a distributor that can supply them.

- Detailed design elaboration, completing the steps from a CyPhy model to the artifacts necessary for the creation of Printed Circuit Boards (PCBs).

2.1.1. The Metamorphosys Tool

Under Google funding, Metamorph has created the Metamorphosys Tool to address the design concerns (see Figure 2). This tool incorporates and extends the OpenMETA framework, tools, and CyPhy language. The extensions are significant, rivaling the capabilities of the core AVM tools.

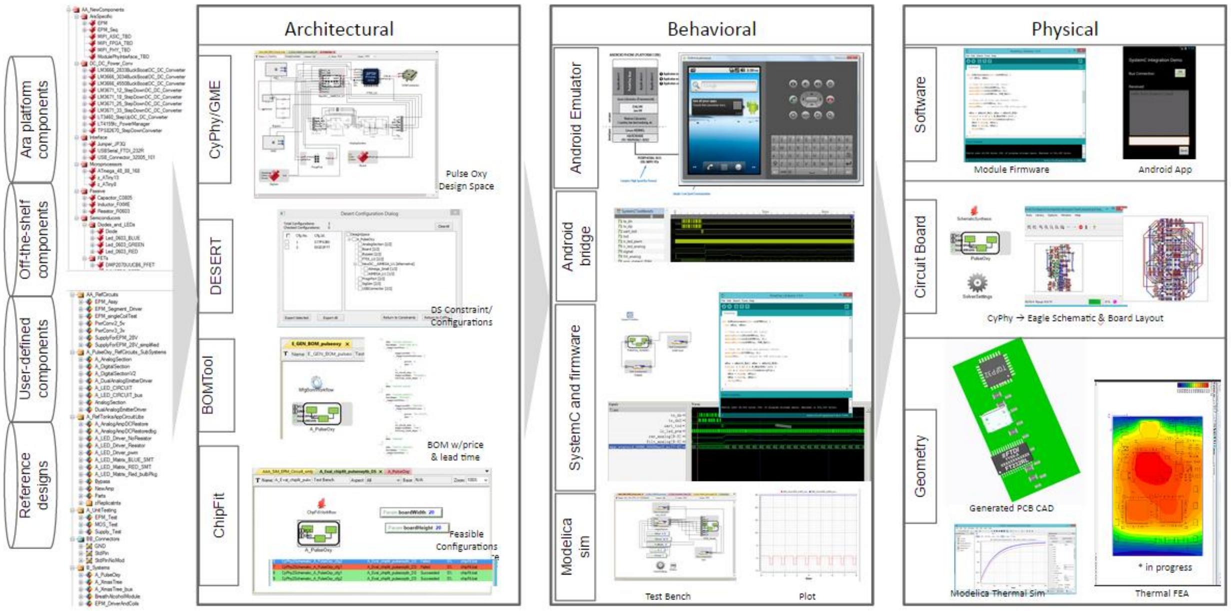

Figure 2: The Metamorphosys Tool Suite

These extensions implemented were to both the CyPhy language and the supporting tools and runtime infrastructure. These are described briefly in the sections below.

The CyPhy Language was extended to support electronic components and systems. Additional concepts were required to capture behaviors in a way that supports different analysis tools and development tasks. These additions for tools and design capture activities are:

- The component model was extended by adding the EagleCAD electronic component physical domain model. This allows capture of device schematics and printed circuit board (PCB) footprint.
- The component model was extended by adding the SPICE electronic behavior domain model. This allows composable behavior for circuits, and efficient simulation of large circuits with the open source NGSpice tools.
- The component model was extended with SystemC digital behavior domain models. SystemC is a highly efficient abstraction of digital circuit behavior, and is used for hardware/software co-simulation.

- The component model was extended by adding OpenEMS Radio Frequency (RF) domain models. These are 3D geometry for the calculation of antenna properties and FCC certification data.
- The capture of software/firmware is represented in the models, allowing for the design and analysis of embedded software and application software.
- The connector concepts were extended, supporting connection of schematic/electrical pins and SystemC ports.

Supporting EDA (Electronic Design Automation) required multiple new tools to be added to the OpenMETA framework. These new composers are briefly listed and described below:

- Composers for analog simulations for Spice tools, including open source NGSpice.
- Composers for Digital hardware simulation for the open-source Accelera SystemC simulation package
- Integration of firmware and app software simulation in conjunction with Digital Simulations.

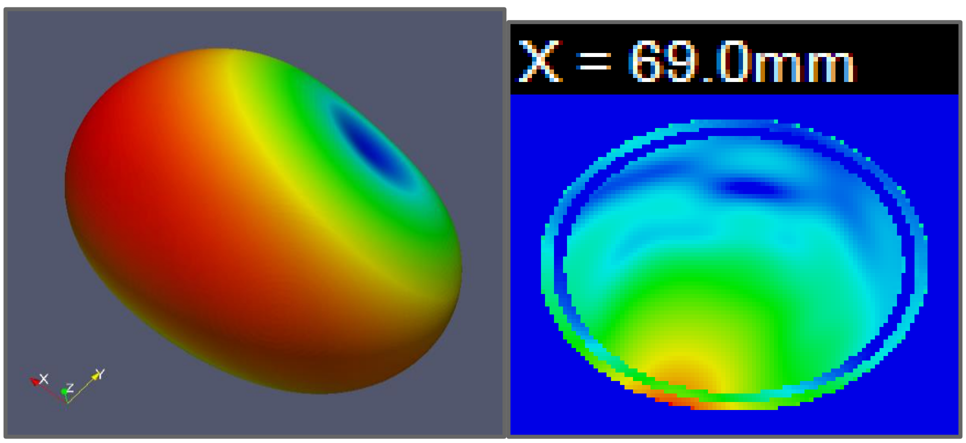

Figure 3: OpenEMS Analysis

- Integration of RF simulations, using OpenEMS to calculate antenna directivity, impedance, phase, and for simulating FCC Specific Absorption Rate (SAR) certification tests (see Figure 3).

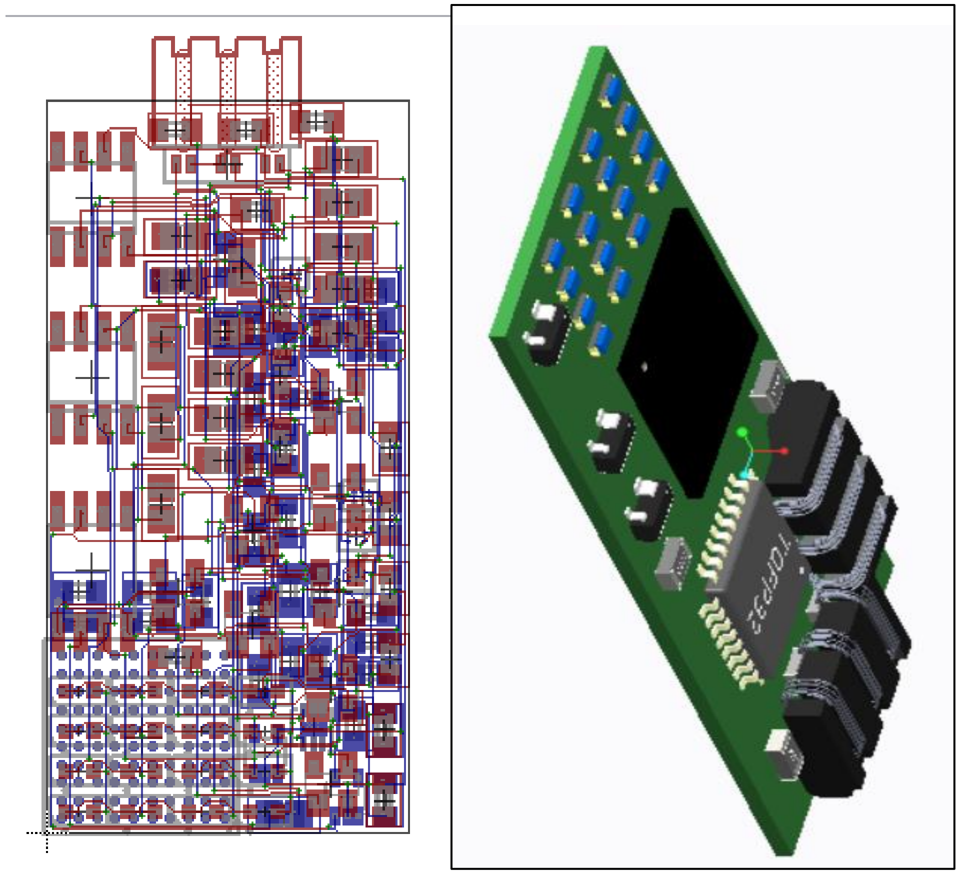

Figure 4: EagleCAD Schematic

- Composers for schematics and printed circuit boards (PCB), supporting creation of EagleCAD schematics and PCBs (see Figure 4).
- Autoplacement tools, to automate the creation of PCB layouts.
- Composers for physical models of the assembled PCB, for interference checks.
- Re-use of the Modelica composer for calculating system thermal properties using lumped parameter models
- Extension of the FEA thermal tools for 3D thermal analysis.

The Manufacturability analysis and execution of iFAB was insufficient for electrical design. For electronics, multiple suppliers are commonly used, with dynamic selection based on price and availability. For the Metamorphosys tool, a dynamic polling of the suppliers was built into the tool, creating a BOM (Bill of Material) with supplier, cost, and availability. An example generated BOM is shown in Figure 5 below.

For the creation of the manufacturing data, in the form of assembled printed circuit boards, a set of standardized design files are created, containing the information needed to construct multi-layer circuit boards, automated drilling of thru-holes and vias, and device placement data for automated pick-and-place machines. With this Technical Data Package (TDP), the PCB can be fully constructed.

Bill of Materials -- ModuleUnderTest

Pricing Time: Monday, November 3, 2014 11:13 AM
Cost per Unit (based on 100 units): $19.19

Show 10 entries

Search:

Item #	Qty	Reference Designator	Manufacturer	Manufacturer Part #	Description	Package	Supplier 1	Supplier 1 SKU	Supplier 1 Price/Unit	Supplier 1 Extended Price	Note
1	1	ARA_Standard_Interface/PSGEN_3p3/DCDC_Conv	Texas Instruments	LM3671TLX-3.3/NOPB	IC REG BUCK SYNC 3.3V 0.6A 5USMD		Digi-Key	LM3671TLX-3.3/NOPBDKR-ND	0.6804	0.6804	Lead Free, RoHS Compliant, Lifecycle Status Active
2	2	ARA_Standard_Interface/PSGEN_3p3/Inductor, ARA_Standard_Interface/PSGEN_1p2/Inductor	Würth Elektronik	768775322	FIXED IND 2.2MH 150MA 7.2 OHM		Newark	32T8675	1.39	2.78	, RoHS Compliant
3	1	ARA_Standard_Interface/PSGEN_3p3/SplitIn									
4	14	ARA_Standard_Interface/PSGEN_3p3/Capacitor_C0805, ARA_Standard_Interface/PSGEN_3p3/C8, ARA_Standard_Interface/PSGEN_1p2/Capacitor_C0805, ARA_Standard_Interface/PSGEN_1p2/C8, ARA_Standard_Interface/EPM_Subsystem/PSGEN_28P0/Capacitor_C0805, MicroControllerSubsystem/Cbp, EKG_Chan/C1, EKG_Chan/C4, EKG_Chan/C3, EKG_Chan/C2, EKG_Chan/C6, EKG_Chan/C7, EKG_Chan/C8, EKG_Chan/c5	Kemet	T488R227M004AAE2K0	CAP, TANT, 220UF, 4V, CASE R	0805	Newark	39X0228	0.684	9.576	
5	1	ARA_Standard_Interface/PSGEN_3p3/SplitOut									
6	1	ARA_Standard_Interface/PSGEN_3p3/ZeroV									
7	1	ARA_Standard_Interface/PSGEN_1p2/SplitOut									
8	1	ARA_Standard_Interface/PSGEN_1p2/SplitIn									
9	1	ARA_Standard_Interface/PSGEN_1p2/DCDC_Conv	Texas Instruments	LM3671TLX-1.2/NOPB	IC REG BUCK SYNC 1.2V 0.6A 5USMD		Digi-Key	LM3671TLX-1.2/NOPBCT-ND	0.6804	0.6804	Lead Free, RoHS Compliant, Lifecycle Status Active
10	1	ARA_Standard_Interface/PSGEN_1p2/ZeroV									

Showing 1 to 10 of 39 entries

Previous Next

Figure 5: Example Bill of Materials

2.2. Components

C2M2L components are not applicable to EDA. Use of C2M2L components were a challenge to use for their intended purpose due to the lack of well-planned interface taxonomy and the lack of comprehensive integration testing, beyond unit tests. Furthermore, the C2M2L library was extremely expensive, considering approximately 60 fully developed component classes were produced at a cost of ~$16M. Clearly, this high cost per component is a threat to the viability of the AVM approach, if this performance translates to other component creators and domains.

Component usability was low for the system designer. Interface naming was non-intuitive, with little indication of interface function from its nomenclature. Components were not designed with usability or reusability in mind. Components had significant problems when composed with other components in the library.

Span of functionality was also low for C2M2L. The component library was primarily a decomposition of two existing designs. Deviation from either of these architectures and exact component uses resulted in incompatible interfaces and failure to simulate without numerical errors. A different approach was needed for Project Ara to enable large design flexibility.

As part of the transition process, a new component library was created, and lessons learned from the AVM C2M2L production and curation process were applied. As part of this process, the component authoring tool was expanded to support the new domains, and to assist in component creation. In addition, a connector taxonomy is being developed to normalize interfaces and their associated semantics.

Concurrent with developing the tools, a library was created with several sets of components. The component library that was created that supports an initial design capability. At the time of this writing, the component set includes:

- > 10000 passive components.
- > 300 complex electronics devices, including microprocessors.
- A range of analog instrumentation and operational amplifiers, transistors, etc.
- A set of power supply converter chips, for the common mobile voltage rails.
- > 100 sensors.
- > 20 Ara-specific connectors, fasteners, shields, etc.

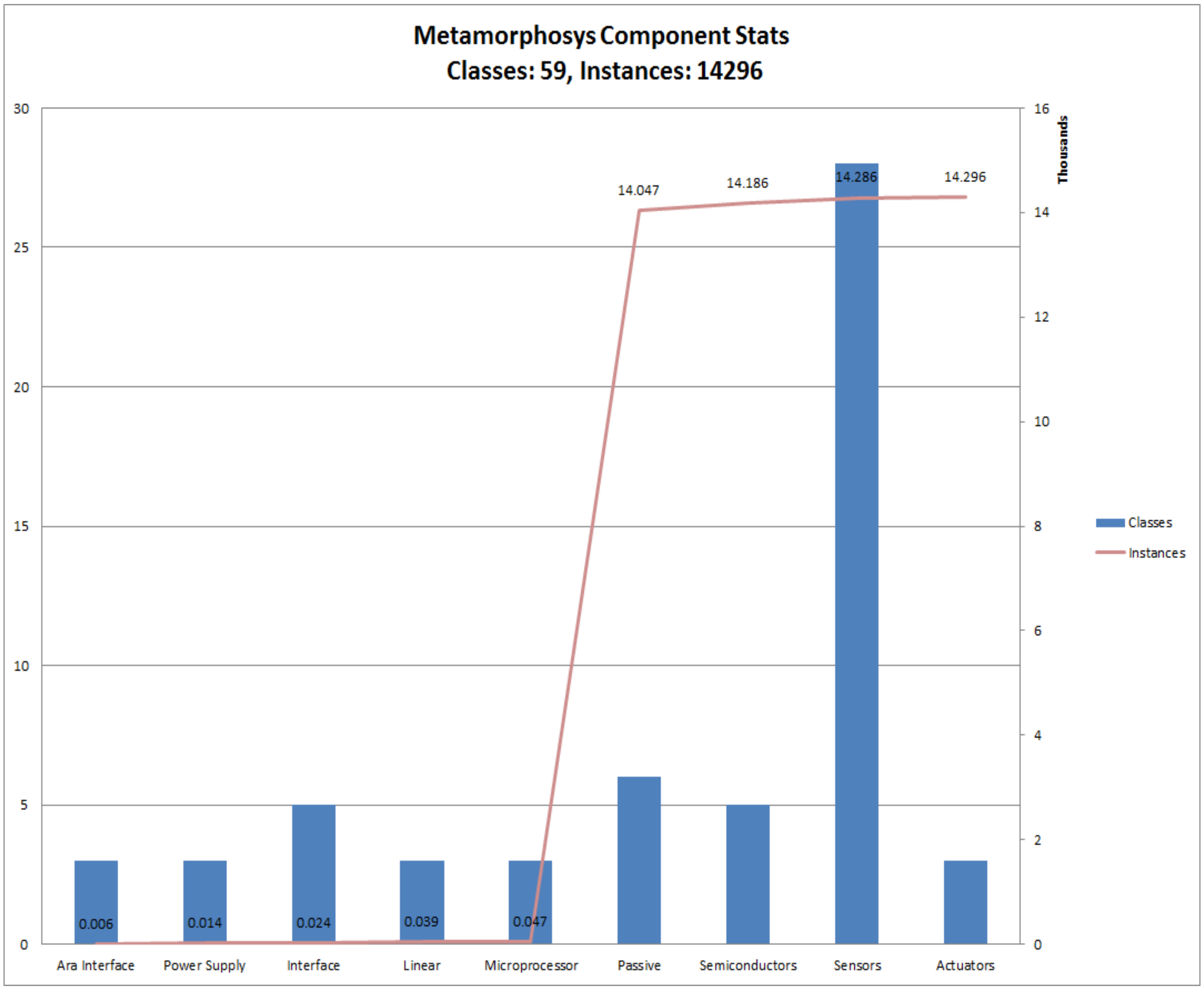

Figure 6: The Metamorphosys Initial Libray (cost <$200k)

Note that the library of Passive components (Resistors, Capacitors, and Inductors) represents a small number of component classes, are highly repetitive, and have been constructed using automated techniques. The more complex components do not follow a pattern, and require significantly more human input per instance (see Figure 6 for a histogram of components by class).

Status:
The tools are open source, at the specification of Google. The tools are in Beta testing, and will be released at the upcoming Google Ara Developers Conference in the 3rd week in January 2015.

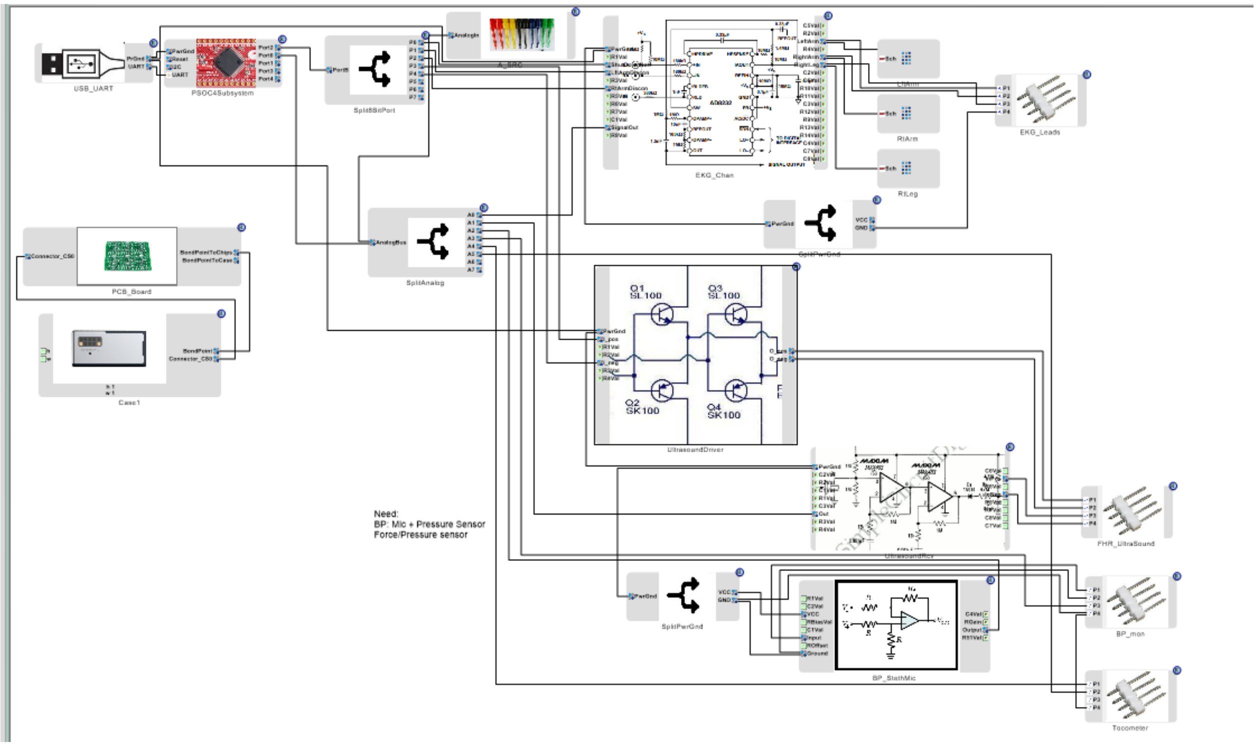

Figure 7: Example Metamorphosys Tool Model

Updates to AVM Component Model and tools performed in the construction of the Metamorphosys tool will flow back to AVM user community. Figure 7 shows an example Metamorphosys model in the EDA domain.

2.3. DMDII - Wind Turbine Blade Design

The OpenMETA tools will be extended under a DMDII effort under a subcontract from GreenDynamics. The market proposition is to produce an integrated tool for design of large wind-turbines. This encompasses several tool efforts:

- Development and integration of a domain-specific user interface front end, to facilitate exploring design spaces of turbine blades.
- Integration of several domain tools for evaluating the dynamic properties of a turbine system

ISIS
Tel (615) 343-7472 Fax (615) 343-7440
1025 16th Avenue South Nashville, TN 37212
www.isis.vanderbilt.edu
VANDERBILT UNIVERSITY

- NREL BladeFS - Structural testing simulator for wind turbine blades using matrix-based finite element analysis
- NRLEL AeroDyn - Aerodynamics analysis routines for horizontal-axis wind-turbine dynamics analyses
- NREL FAST – Aero-elastic computer-aided engineering (CAE) tool for horizontal axis wind turbines

- Model Geometry Synthesis: The CAD Composition tools will be extended to support component synthesis for blade specifications generated from the NREL tools.
- Integration of Composite Design Tools
  - PATRAN will be integrated to allow specification of composite layups.
  - The FEA solution composition will be extended to support NASTRAN composite FEA.

Transition target: Companies that specialize in the design of turbine blades will leverage these tools to provide value in terms of more optimal designs and significantly reduced design cycles and time-to-market.

Status: under funding negotiation.

2.4. Oshkosh

Oshkosh Corporation designs and builds specialty trucks, military vehicles, truck bodies and access equipment. Oshkosh was a participant in the FANG 1 competition and the gamma test, and consequently has a deep understanding of the OpenMETA tools.

Oshkosh is interested in applying the tools for concept study and design architecture tradeoffs, with transition to deep analysis. Given the competition to provide reliable, efficient, highly functional equipment at the lowest possible cost, companies like Oshkosh must constantly evaluate technologies and design options across the product line. In addition, niche, non-commodity products can be profit centers if the non-recurring engineering costs can be minimized.

Specific tools of interest to equipment designers include:

- Design Space modeling and discrete design space exploration, considering component and subsystem alternatives
- Dynamics simulation
- CAD Assembly
- FEA
- Collaborative design editing and construction.

Status: Ongoing discussions planning a seed deployment of OpenMETA tools at Oshkosh.

3. Defense/Government Transitions

Raytheon Missile Systems is engaging Vanderbilt in a small support contract for supporting OpenMeta tool evaluation.

4. Transition to the Research Community

A proposal is underway to create a series of OpenMETA based collaboration and computation facilities, in conjunction with the Cyber Physical Systems Virtual Organization (CPS-VO). The CPS-VO is an umbrella organization to foster collaboration among CPS professionals in academia, government, and industry.

Currently, the CPS-VO functions as a collaboration site and repository for exchange of project goals, status, and shared code. Plans call for the CPS-VO to grow into a more collaborative development environment, with opportunities to support common code, data, and execution environments across geographically distributed teams, and to encourage tool integrations.

This effort will leverage two main AVM products: VehicleForge (VulcanForge) and OpenMETA. The planned architecture is shown below in Figure 8. The CPS-VO infrastructure will continue to be the human-centered collaboration site, with extensions to support more design detail publication and exchange. VehicleForge will support a similar function as in AVM, as the host for detailed project collaboration on an engineering level, with extensions to support flexible, selective publication of results up to the CPS-VO. OpenMETA tools will be used inside the VehicleForge instances, with a certain amount of customization for different communities focused on individual domains.

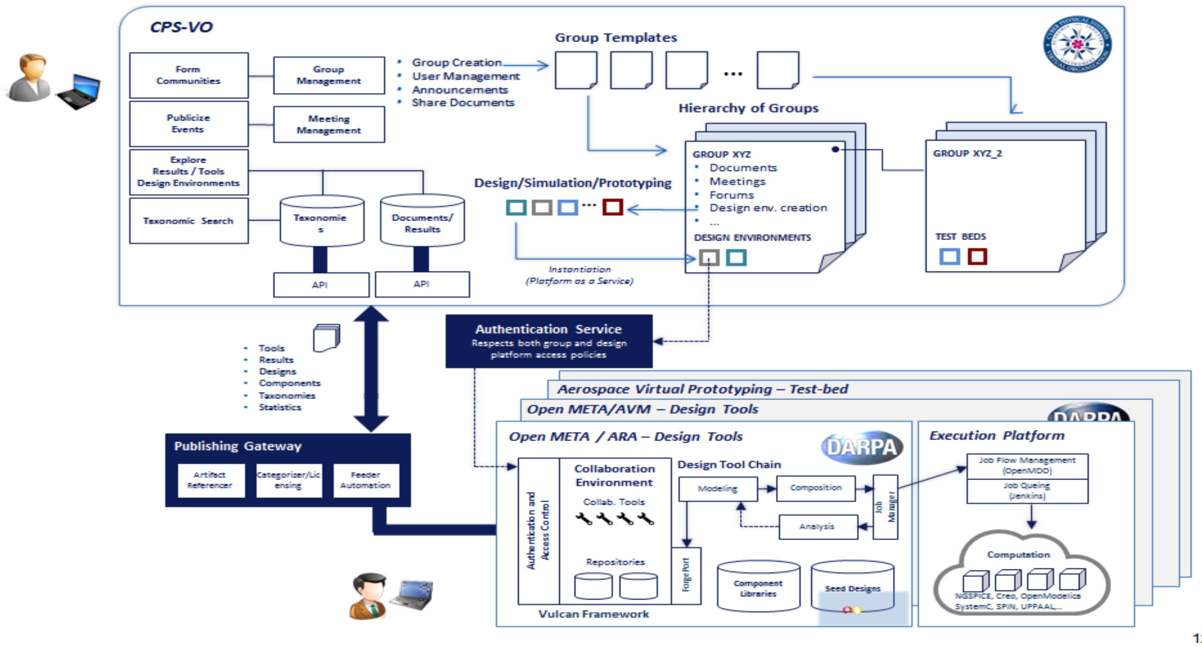

Figure 8: CPS-VO Domain Communities

Domain communities will include:

- Mobile Electronics, using the Google-Ara EDA tools and component libraries
- Heavy Machinery, using the core AVM tools
- Medical Electronics, using EDA tools and medical focused libraries
- Aerospace Systems, using META and other tools from University of Pennsylvania

Long-term plans are to encourage OpenMETA to be used as a tool integration platform for researchers. Researchers will benefit from the available component libraries, model editing capabilities, and the baseline integrated tools, such as dynamics simulation, CAD composition, FEA/CFD, Spice simulation, etc. The researchers will also gain a vector for distribution of research results and access to potential customers/funding sources that can apply specialized design tools.

5. Transition Common Themes and AVM Goals

The transition activities represent a range of transition vectors, with several common themes:

- **Component-Based Design**: The AVM precept of investing in highly functional components, with multiple physics-based abstractions, multiple tool domains, and multiple fidelities is a major advantage expected during almost all of the transitions. This is particularly the case for the EDA, the Oshkosh, and the research platform.

- **Executable Requirements and Tool Automation**: The ability to map a common model directly to an analysis tool without expertise with the domain tool is a driving factor. This is a major contributor to "Democratization of Design". Under AVM, a useful set of these mappings were created, covering simulation, geometry, and finite element analysis, which apply to all transitions. The infrastructure, both in components and in model management & mapping provided an efficient, low effort mechanism to support other tools. The EDA case illustrates this ability to add new tool support (Schematic/PCB, Spice, SystemC, RF analysis, etc.) while fully exploiting the existing Modelica and FEA capabilities.

- **Component Library Affordability**: All of these transitions, with the exception of the Green Dynamics, rely on pre-built component libraries or the ability to build-out libraries for specific applications. The solution is a combination of both procedural and automation tools. The EDA transition effort includes a range of components that are both automatically generated and an active component development staff effort. For Oshkosh, component libraries will be inexpensively created leveraging existing tool artifacts.

- **Design Adaptability**: Design space construction and exploration are key selling points for the transition efforts. EDA is an optimization process, across the design space of specific circuits and devices, package options, and target form factors. Adaptability is important to reduce time-to-market while following external platform specifications. Oshkosh explores design spaces of components, architectures, and physical component sizes to maximize utility for a market while minimizing cost. A common architecture that satisfies multiple specific customer needs minimizes NRE costs and maintains a brand image, meets changing customer goals in a short time, and maintains consistent quality.

6. Conclusions

Overall, the transition efforts show that the results of META are valuable and applicable to both defense and commercial applications. The commitment of industry is shown by the commitment of resources, in external funding and internal engineering efforts.

Many of the individual efforts can realize a benefit that matches DARPA's investment in META. The transition efforts are expected to be expanded into several other DoD and industry projects, as well, some of which cannot be discussed due to proprietary constraints.