OpenCPI - Open Component Portability Infrastructure

An Open Source Framework for Heterogeneous/Embedded Component-Based Systems and Applications

Introduction to OpenCPI Development for Application and Component Developers

Objectives

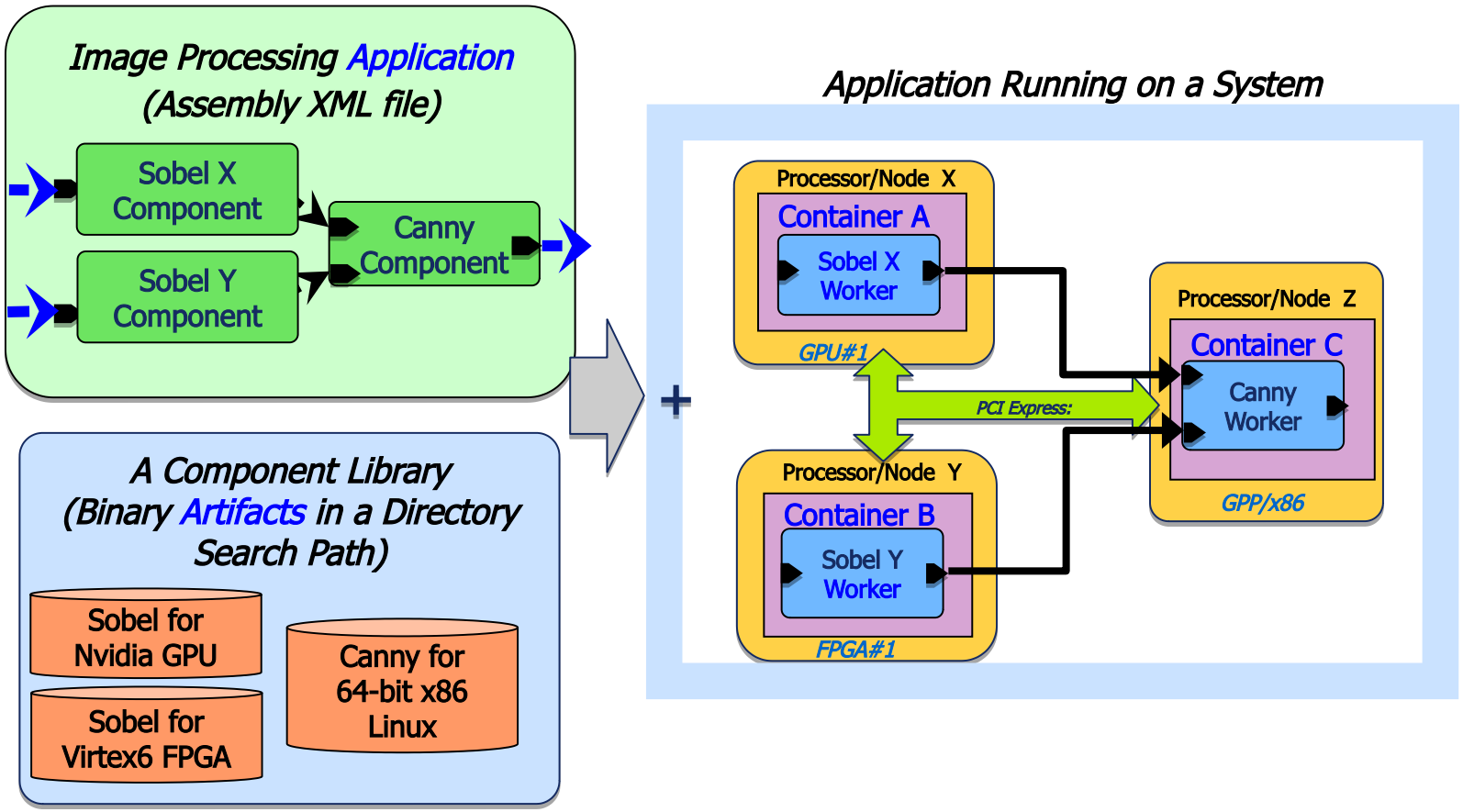
- This briefing describes OpenCPI from the *development perspective*. It:
  - Describes how the elements needed for execution of an OpenCPI application are created.
  - Defines OpenCPI terminology and concepts that apply to application and component development.
  - Introduces tools used for development.
- This briefing is introductory, not comprehensive.
- A prerequisite for this briefing is the previous "Introduction to OpenCPI" briefing.

Concepts for OpenCPI Development

- ***Development*** is producing things needed for execution.
- The previous briefing defined things *needed* for execution of an ***application***. These are:
  1. The application itself, defined as an assembly XML file that describes an assembly of ***components***.
  2. Artifact libraries that consist of (binary/executable) ***artifacts*** compiled from ***workers*** that implement requested components.
  3. Runtime environments called ***containers*** that can load and run the artifacts (and thus workers) needed by the application.

Needed: Application XML+Artifacts+Containers

- Execution requires: application assembly + artifact libraries + containers



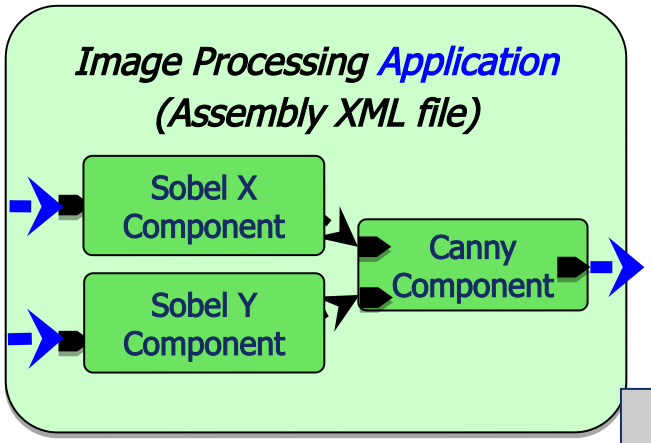
Who creates these things and how?

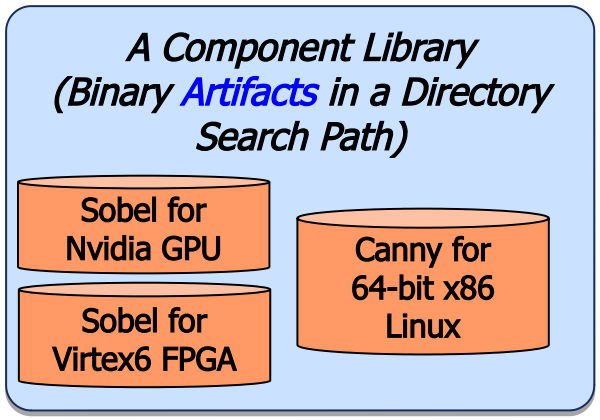
Who Develops What's Needed?

- Different developer types/roles contribute to what's needed for application execution:
  - ***Application*** developers create ***applications*** that specify ***components*** and use ***artifacts*** to execute on ***containers***.
  - ***Component*** developers create ***components***, ***workers*** and ***artifacts*** for use by application developers.
  - ***Platform*** developers create the lower level drivers and configurations that support the ***containers*** (runtime environments on processors) in a system.
- OpenCPI provides a reference manual for each developer type.

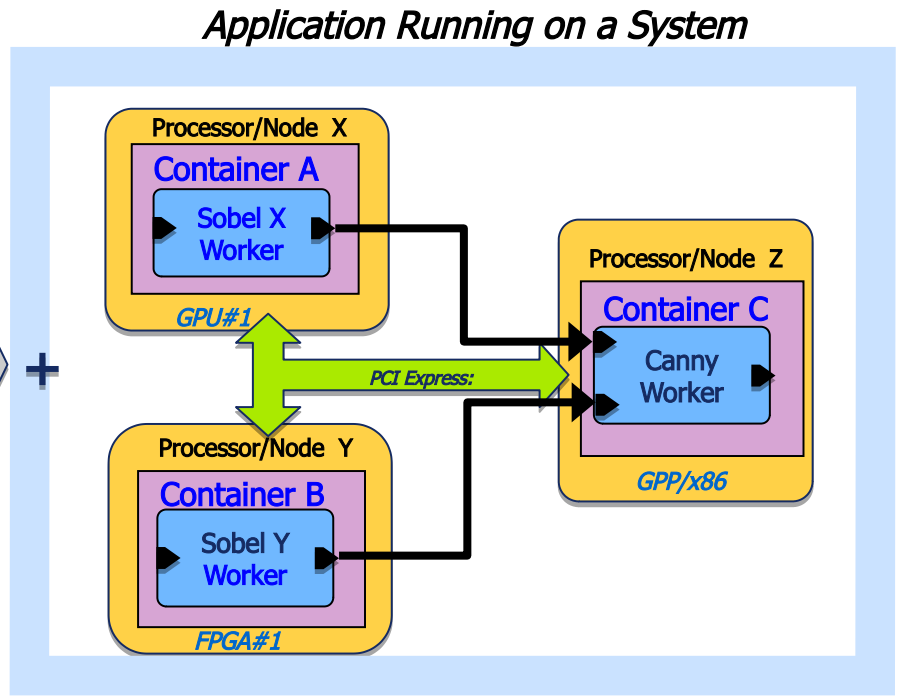
Developer Roles in Providing What's Needed

Application Developers
provide application XML





Component Developers provide components, workers, artifacts



Platform Developers provide containers

OpenCPI Terms for Application Developers

- ***Applications:*** are defined as an:
  - ***Assembly:*** of configured and connected components
- ***Components:*** are defined functions which have:
  - ***Properties:*** that configure and control the component, and
  - ***Ports:*** where data messages are sent and received, and which support:
    - ***Protocols:*** which define the allowed/expected messages
- ***Workers:*** are implementations (source code) of components
- ***Artifacts:*** are binary executables compiled from one or more workers
- ***Containers:*** are runtime environments for executing workers
- ***Asset:*** a general term for anything developed for OpenCPI
- ***Project:*** a workspace in a directory where assets are developed

OpenCPI Project: Workspace for Developers

- The term ***asset*** is used for things created by all (3) types of developers.
  - applications, components, workers, artifacts, protocols etc.
- The term ***project*** is used for an OpenCPI workspace (in a directory/folder) where all types of developers create assets.
  - My project can be declared to depend on your project:
    - I can create an application in my project that depends on components and workers in your project.
  - One project can contain all types of assets.
  - One project can contain multiple assets of any type.
- The work product of developers is ***projects*** containing ***assets***.
- ***Projects*** are in the development environment:
  - They do not exist in a runtime-only (i.e. deployed) environment.

OpenCPI Assets

- The general term for things that are developed in projects:
  - components, protocols, workers, applications, and many more (but not artifacts; they are not assets)
- Most assets are defined by an XML file
- Most asset types have their own directory
  - So the XML file lives there
  - Other files for the asset also live there, e.g. source code
- Things a developer does with assets
  - Create and destroy
  - Edit/modify
  - Build and clean (for some types, like workers)
  - Run (for some types, like applications and unit tests)
- Application developers generally
  - Rely on component developers to supply components and artifacts
  - Read (but do not create) component specifications (XML)
  - Create application assembly XML

What is XML?

- For those not familiar
- XML stands for e**X**tensible **M**arkup **L**anguage
- A structured type of text file containing a hierarchy of ***elements***
- So the file is an ***element***, and that element can have ***child elements***
- Each element has a type identifier and named ***attributes*** w/values
- Elements look like this (e.g. for a protocol, consisting of operations)

```
<protocol>
  <operation name='op1'/>
  <operation name='op2'/>
</protocol>
```

- So the file has a **`protocol`** element with **`operation`** child elements
  - The **`operation`** elements each have a name attribute
  - An element that has no children can end in: **`/>`**
  - An element that has children ends in: **`</type>`**

OpenCPI Development Tools

- The **`ocpidev`** command-line tool performs operations on assets:
  - Operations (verbs) are: create, delete, build, clean, run, show
  - Except for projects, all operations are on assets in projects
  - Its syntax is:
    - **`ocpidev`** *[<options>...] <verb> <asset-type> <name>*
    - E.g.: **`ocpidev create application myapp`**
  - Compilers and FPGA tools are used by **`ocpidev`** for building
- Asset XML and source code are modified using text editors
- There is also the OpenCPI GUI asset development tool:
  - It also performs operations on assets, but with fewer options
  - It calls/uses **`ocpidev`** to get everything done

OpenCPI Artifacts: OpenCPI's "binaries"

- Artifacts are the result of building workers, by component developers
- They are *not* "assets", they are the *result* of building assets
- They may or may not be in projects
  - they are initially created in projects
- They are files containing executable code for one or more workers
  - Targeting a specific execution platform/processor, including FPGAs.
  - Loaded into a container to execute those workers for an application.
- They have embedded OpenCPI metadata
  - The metadata describes the workers that were compiled to make them
- For software workers they are roughly like .so or .dll files
- For FPGA workers they are roughly like "bitstream" files
- When an application is run, artifacts are "sought" by looking in directories specified by OCPI_LIBRARY_PATH
  - Analogous to PATH or LD_LIBRARY_PATH on Linux

Assets for Application Development

- Component, Protocol and Application assets are the main building blocks for application development.
- All of these assets are XML.
- Components (a.k.a. "specs" or "component specs")
  - What an application developer ***reads*** to know how to use components
  - The building blocks for applications
- Protocols, used by ports in component specs.
  - Describes what messages a component sends or receives on a port
  - Applications connect ports (of components) whose protocols match
- Applications (the "assembly of connected components")
  - Describes which components should be used
  - How they are configured (via properties)
  - How they are connected (via ports)

Asset Type: Component

Term: *Component*

Definition: A specific function used when composing applications and a "contract" for workers (implementations)

Described by: an OpenCPI Component Specification (OCS) XML file
a.k.a. "component spec"

Example: FIR Filter

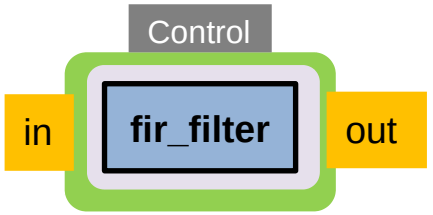
Features of Components

- *Property* – configurable value used to control the component's operation
  - — Controlled at runtime, via:
    variable in C/C++, register in VHDL
  - --or--
  - — Controlled at build time, via:
    `static const` in C/C++
    `generic` in VHDL

- *Port* – an interface used to communicate with other components
  - — *protocol* attribute indicates protocol
  - — *producer* attribute indicates direction

Example OCS

```
<ComponentSpec>
  <Property Name='numberOfTaps'
            Parameter='true'/>
  <Property Name='taps'
            ArrayLength='numberOfTaps'/>
  <Port Name='in' Producer='false'
        Protocol='iq_with_time'/>
  <Port Name='out' Producer='true'
        Protocol='iq_with_time'/>
</ComponentSpec>
```



Asset Type: Protocol

Term: *Protocol*

Definition: Description of a set of messages that may flow between the ports of components

Described by: an OpenCPI Protocol Specification (OPS) XML file
a.k.a. "protocol spec"

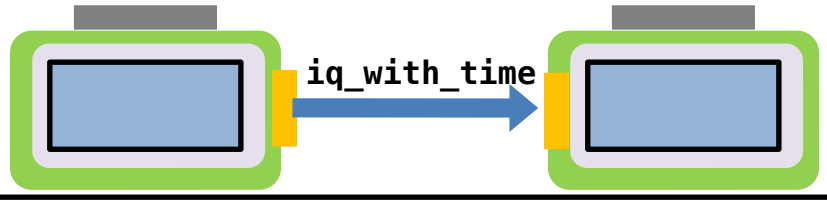
Example: iq_with_time

Features of Protocols

- *Operation* elements describe the messages that may be used
- *Argument* elements describe the individual fields of a message
- The protocol is specified in the Port element of a component spec (OCS)

Example Protocol Specification XML

```
<Protocol>
  <Operation name='iq'>
    <Argument name='data' type='struct'>
      <member name='i' type='short'/>
      <member Name='q' type-'short'/>
    </Argument>
  </Operation>
  <Operation name='time'>
    <Argument name='time'
              type='ulonglong'/>
  </Operation>
 </Protocol>
```



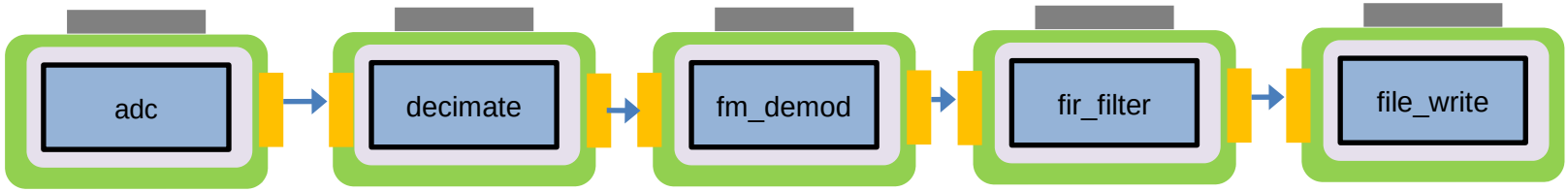
Asset Type: Application

Term: *Application*
Definition: Connected/configured assembly of components
Described by: an OpenCPI Application Specification (OAS) XML file, a.k.a. "App XML"
Example: FSK Demodulator

Features of Applications:

- Instances of components are indicated by *instance* elements
- Instances have *property* child elements to "configure the instance"
- Instances are connected in various ways, usually with the *connect* attribute

Application



Application Specification XML

```
<Application>
  <Instance component='adc'         connect='decimate'/>
  <Instance component='decimate'    connect='fm_demod'/>
  <Instance component='fm_demod'    connect='fir_filter'/>
  <Instance component='fir_filter'  connect='file_write'/>
  <Instance component='file_write'/>
</Application>
```

Summary of Concepts for Application Developers

- Application developers create the application assembly XML that uses components and artifacts created by component developers, which run on containers created by platform developers.
- An application is an OpenCPI asset developed in an OpenCPI project.
- An application is developed with the OpenCPI `ocpidev` command line tool and/or the OpenCPI GUI.
- Applications use components which in turn use protocols. All of these assets are described in XML files.
- A component may have properties to control its operation and ports for communicating with other components. A port identifies its protocol and the direction of data flow.
- A protocol asset has operations to identify the types of messages that may be used and arguments to describe individual message fields.
- An application has instances to specify component instances and property values for configuring the instance. Instances can be connected.
- An artifact is the result of building a worker, which is an implementation of a component. An artifact is not an asset.

OpenCPI Component Development

- Component development creates the assets and artifacts needed to define and run applications, and encompasses:
  - Specifying the component and protocol assets (in XML files)
  - Creating workers that implement the component and protocol specs
  - Building workers into artifacts (using authored source code)
- Workers are assets with their own directory, XML and source code
  - The XML refers to the component spec and describes implementation details
  - The source code, in a language like C++ or VHDL, implements the spec
- Components/protocols/workers are created in component Libraries
  - A directory structure holding components, protocols and workers
- Libraries/components/protocols/workers created/deleted by **`ocpidev`**
- Component libraries and workers are *built* by **`ocpidev`**
- All these assets are created in OpenCPI projects.

Asset Type: Worker

Term: *Worker*

Definition: A concrete implementation of a component, with source code

Described by: OpenCPI Worker Description XML (OWD), in a worker's directory

Other Files: Makefile, source code file(s)

Examples: fir_filter.rcc, fir_filter.hdl

Features of Workers

- Worker name suffix indicates *authoring model* — *the API and language for the source code*
  - **`<worker>.rcc`** for C/C++
  - **`<worker>.hdl`** for VHDL
- Worker description XML (*OWD*) indicates
  - Which component spec (OCS) is implemented
  - Which language is used for source code
  - May contain additional properties & port information to expand or refine OCS

Example:

One *OCS* ⇨ Two Workers

- **`fir_filter.hdl/`**

  OWD file: **`./fir_filter.xml`**

```
<HdlWorker spec='fir-spec'
           language='vhdl'/>
```

  Source file: **`./fir_filter.vhd`**

- **`fir_filter.rcc/`**

  OWD file: **`./fir_filter.xml`**

```
<RccWorker spec='fir-spec'
           language='c++'/>
```

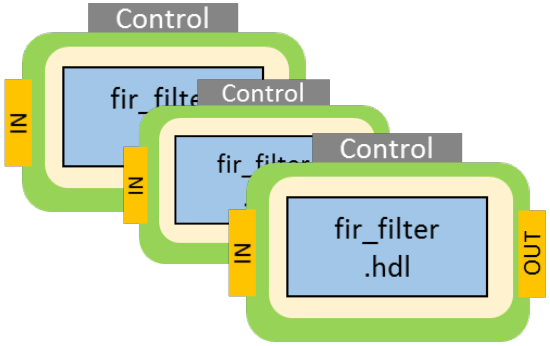
  Source file: **`./fir_filter.cc`**

Asset Type: Component Library

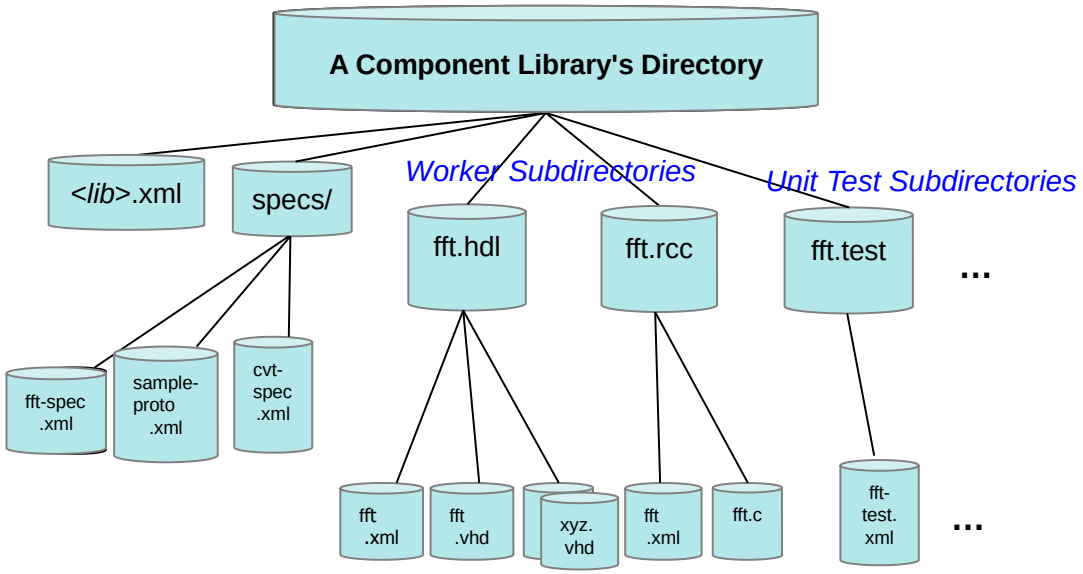
Term: *Library*
Definition: A related set of components in a single directory in a project
Described by: Directory structure and Makefile, no XML for the library
Contains: Component and Protocol Specs, Workers and Unit Tests
Example: "Utility" Components

Features of Component Libraries

- Provide a logical grouping
- Reduces clutter
- Encourages reusability
- Built time search rules



Example directory structure:



Asset Type: HDL Assembly

Term: *HDL Assembly*

Definition: A group of pre-connected HDL/FPGA workers built as an artifact. intended to be used as a FPGA-based subset of an application

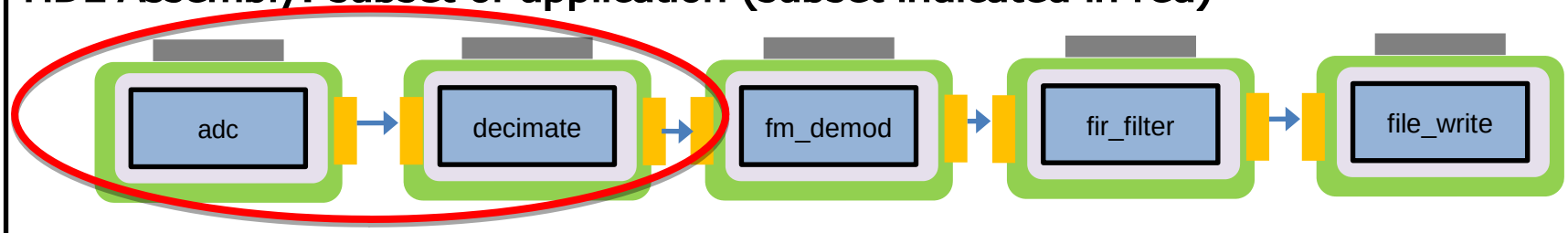
Described by: OpenCPI HDL Assembly Description XML (OHAD)

Other Files: Makefile

Features of HDL Assemblies:

- Instances of *workers* are indicated by ***instance*** elements
- Instances may have ***property*** child elements for build-time property values
- Instances are connected in various ways, usually with the ***connect*** attribute

HDL Assembly: subset of application (subset indicated in red)



HDL Assembly Description XML

```
<HdlAssembly>
  <Instance worker='adc'          connect='decimate'/>
  <Instance worker='decimate'     externals='true'/>
</HdlAssembly>
```

Try What You've Learned

- After reading this briefing, you should be familiar with the terms, concepts, tools and assets related to introductory application and component development.
- You can try out what you've learned here by following Tutorial 1, "Introduction to Component Development".
  - One version is for command-line tool usage only
  - Another is for GUI usage.