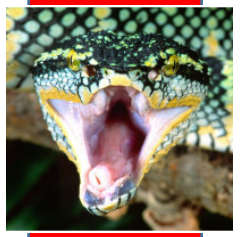
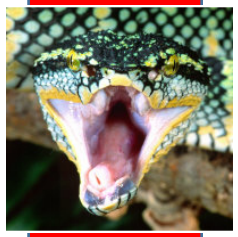


Component & Worker Development Overview

Outline

- Acronyms
- Component vs. Worker vs. Authoring Model
- Example: Creating an OCS & OWD for a Boom Box
- Control Plane & Worker LifeCycle
- Properties (Configuration)
  - Accessibility Rules, Common Attributes, Parameter Attribute, Types
- Ports
- Protocol
- App Worker Development Workflow



List of Terms

Application

Component

Worker

Authoring Model

Protocol

Platform

Container

HDL Assembly

HDL Platform

Control Plane

Data Engine/Plane

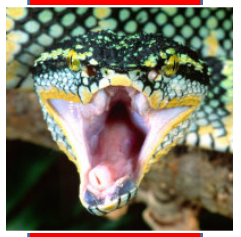
Application Worker

Device Worker

Platform Worker

Artifact

Acronyms

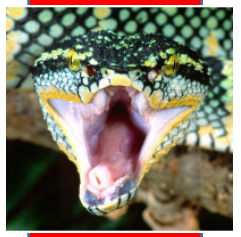


- CDG – OpenCPI Component Development Guide
- RDG – OpenCPI RCC Development Guide
- HDG – OpenCPI HDL Development Guide

- RCC – Resource-Constrained C/C++ Language (Authoring Model)
- HDL – Hardware Description Language (Authoring Model)

- OPS – OpenCPI Protocol Specification
- OCS – OpenCPI Component Specification
- OWD – OpenCPI Worker Description

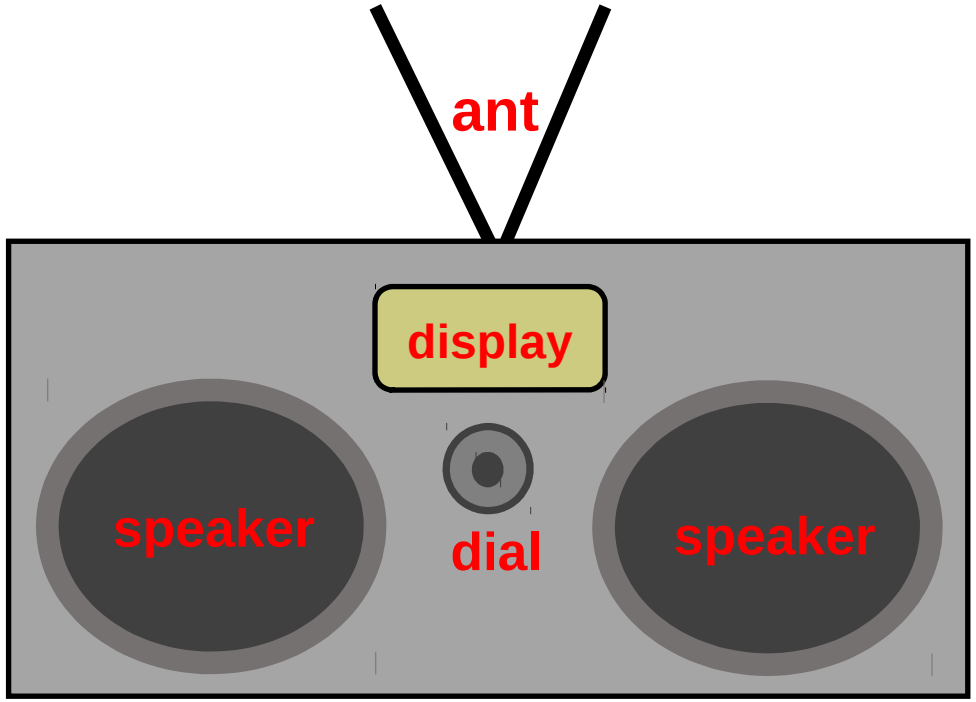
Component vs. Worker vs. Authoring Model



- Component
  - "...encompass the functionality and abstract interface aspects of a model."
  - Specifies the Ports and Properties of a Function (ex. FIR filter, CIC interpolator/decimator)
  - Is a **"Contract"** or minimum set of requirements *all* Workers must respect
  - Described in the OpenCPI Component Spec (OCS) XML or "Spec" file
- Worker
  - Specific implementation of a Component, which must respect the "**Contract**" with source code written according to an Authoring Model
    - **MAY** ADD capability to Component (Attributes of Ports and Properties) but **MAY NOT** REMOVE
  - May ADD properties (i.e. unique to Worker)
  - Multiple Workers may implement a single Component
    - Typically when targeting different technologies: GPP and FPGA
    - Example: Component-a is implemented by workera1.rcc, workera2.rcc, workera1.hdl, workera2.hdl
  - Described in the OpenCPI Worker Description (OWD) XML, Makefile and source code, and -build.xml
- Authoring Model - "a way to write a Worker"
  - Language used to implement a Worker, directly related to target technology
  - GPP ⇨ C or **C++** ⇨ RCC Workers (worker.rcc) and FPGA ⇨ VHDL ⇨ HDL Workers (worker.hdl)

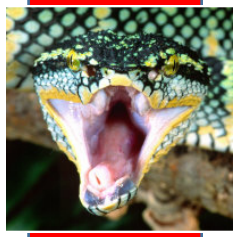
Example: Component

- What is the function? **Boom Box**
- What are the input and output ports? **ant, speaker(s)**
- What are the properties? **display, dial**

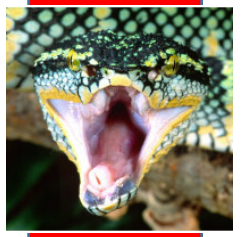


OCS or “Spec” file ⇨ **“boombox-spec.xml”**

```
<ComponentSpec>
  <Port Name=“ant” Producer=“false” Protocol=“rx-prot”/>
  <Port Name=“speaker” Producer=“true” Protocol=“audio-prot”/>
  <Property Name=“display” Type=“float” Volatile=“true”/>
  <Property Name=“dial” Type=“float” Writable=“true”/>
</ComponentSpec>
```

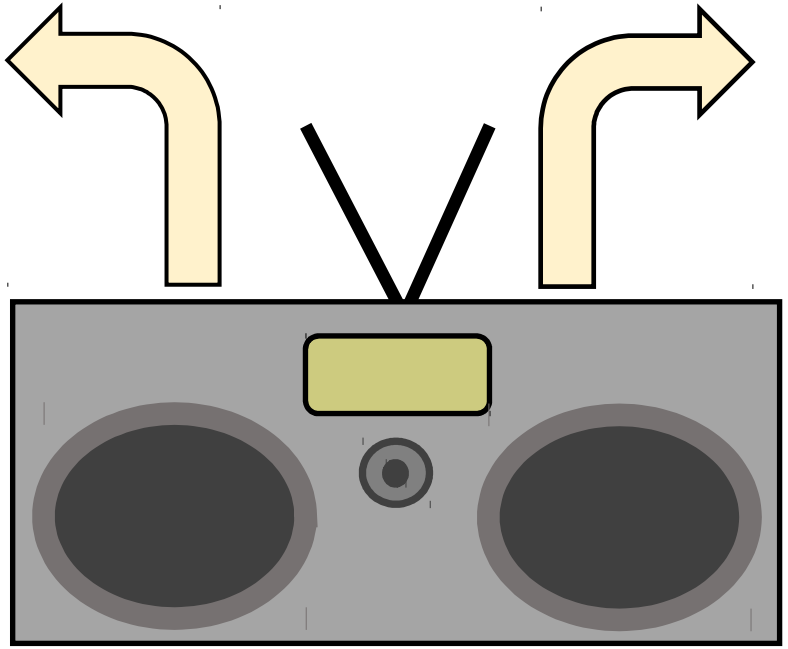


Example: Authoring Models



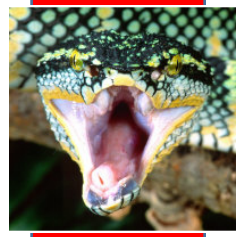
- Suppose there are two different technologies for which the Boom Box will be implemented, one on a GPP and the other on an FPGA
- Worker is created for a specific technology or ***Authoring Model***
  - .hdl, .rcc

RCC



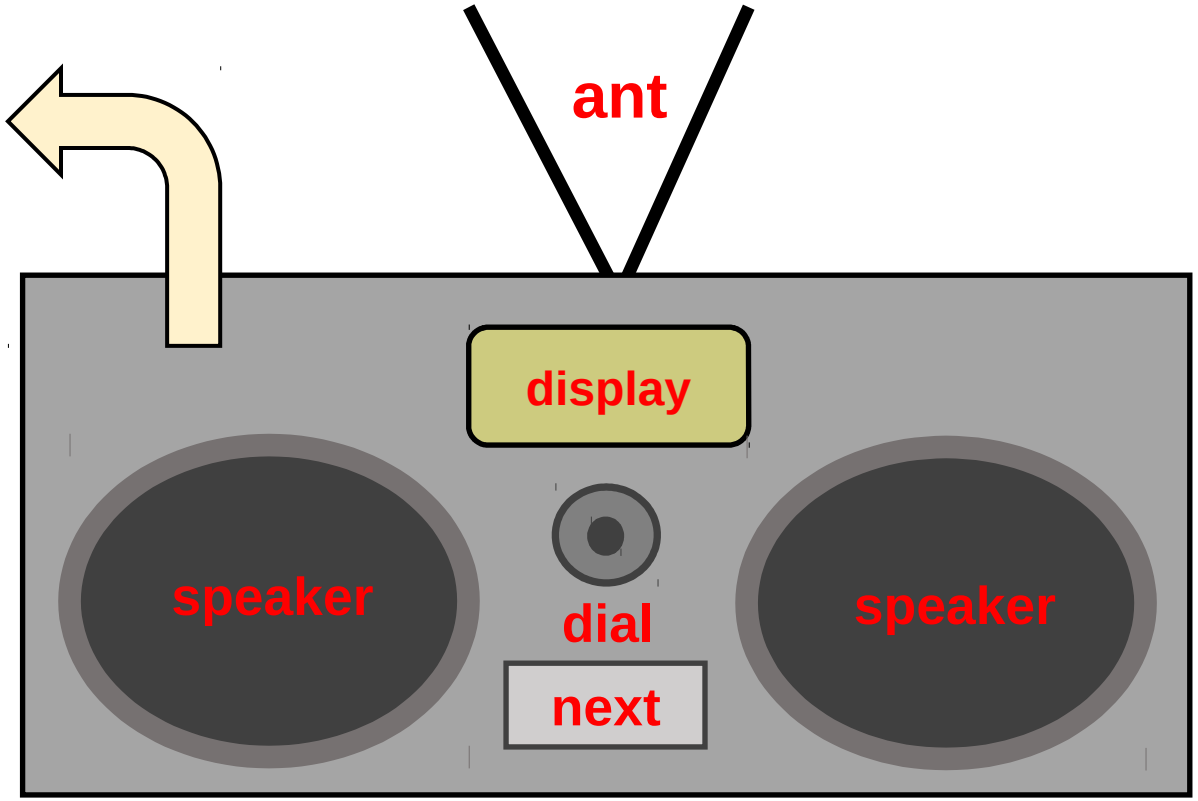
HDL

Example Boom Box: Worker 1

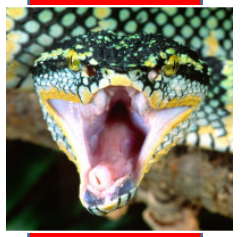


- Worker 1 targets a technology that supports a “next” channel scan feature. This capability will require a new property to be added to *this* worker, in addition to OCS's properties.

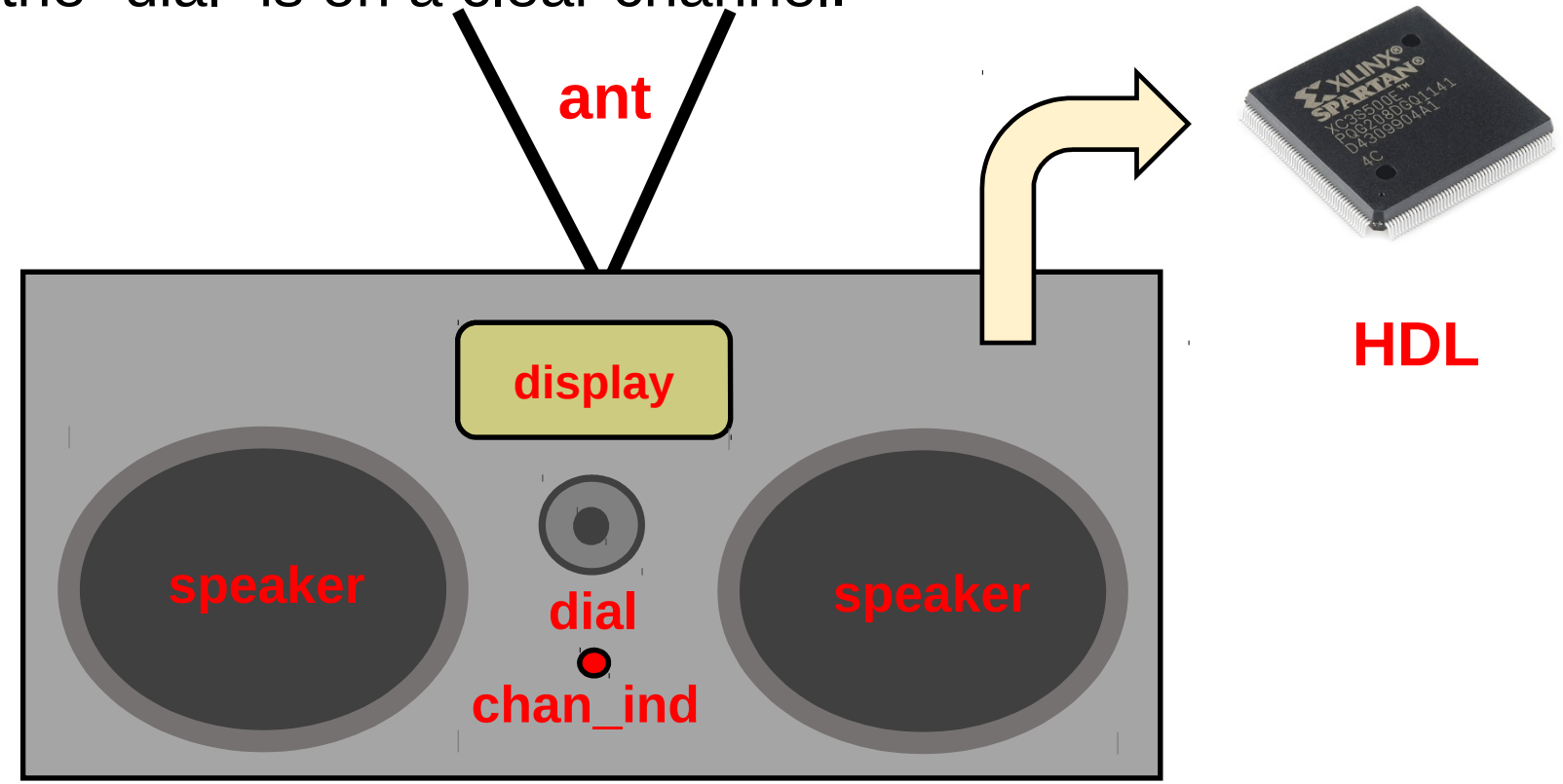
RCC



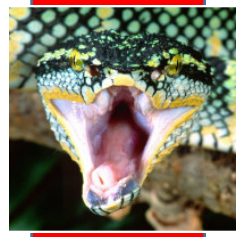
Example Boom Box: Worker 2



- Worker 2's target technology is different from Worker 1. Its technology requires defining physical data widths on the ports. It supports unique properties: channel indicator, “chan_ind”, an LED indicating to the user that the “dial” is on a clear channel.



Example: Workers



- Described by their OpenCPI Worker Description (OWD) XML, Makefile, and source code

- For GPP, RCC Worker

  - *…/worker.rcc/worker.xml:*

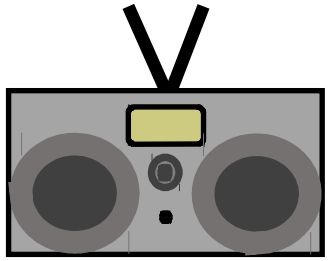
```
<RccWorker language='c++' spec=boombox-spec>
    <Property Name="next" Type="Boolean"
    Writable="true"/>
</RccWorker>
```

- For FPGA, HDL Worker

  - *…/worker.hdl/worker.xml:*

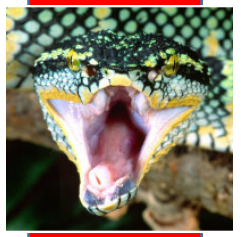
```
<HdlWorker language='vhdl' spec=boombox-spec>
    <StreamInterface Name="ant" DataWidth=32 />
    <StreamInterface Name="speaker" DataWidth=16 />
    <Property Name="chan_ind" Type="Boolean" Volatile="true"/>
</HdlWorker>
```

specs/boombox-spec.xml:



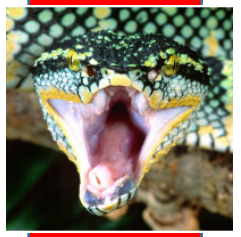
```
<ComponentSpec>
  <Port Name="ant" Producer="false" Protocol="rx-prot"/>
  <Port Name="speaker" Producer="true" Protocol="audio-
prot"/>
  <Property Name="display" Type="float" Volatile="true"/>
  <Property Name="dial" Type="float" Writable="true"/>
</ComponentSpec>
```

More on Authoring Models



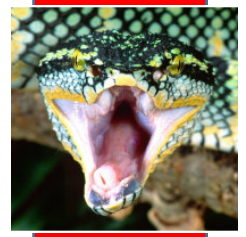
- Since there's no one language, or API, to target all processing technologies:
  - Define a set of Authoring Models that achieve native efficiency with sufficient commonality to allow:
    - Efficient use of target processors development language: C++ for GPP, VHDL for FPGA
    - Replace component's Authoring Model within an Application without negative impact
    - Combine workers into Application using multiplicity of Authoring Models/processing technologies
- Specifies how a Worker is written, built and packaged for execution in an Application
  - RCC: Execute on GPPs (General Purpose Processors), written in C or **C++ (focus)**
  - HDL: Execute on FPGAs (Field-Programmable Gate Array), written in **VHDL (focus)**
    - currently, VHDL is the only supported HDL Worker authoring language (limited support for Verilog)
    - primitives may be written in either VHDL or Verilog

Control Plane Introduction

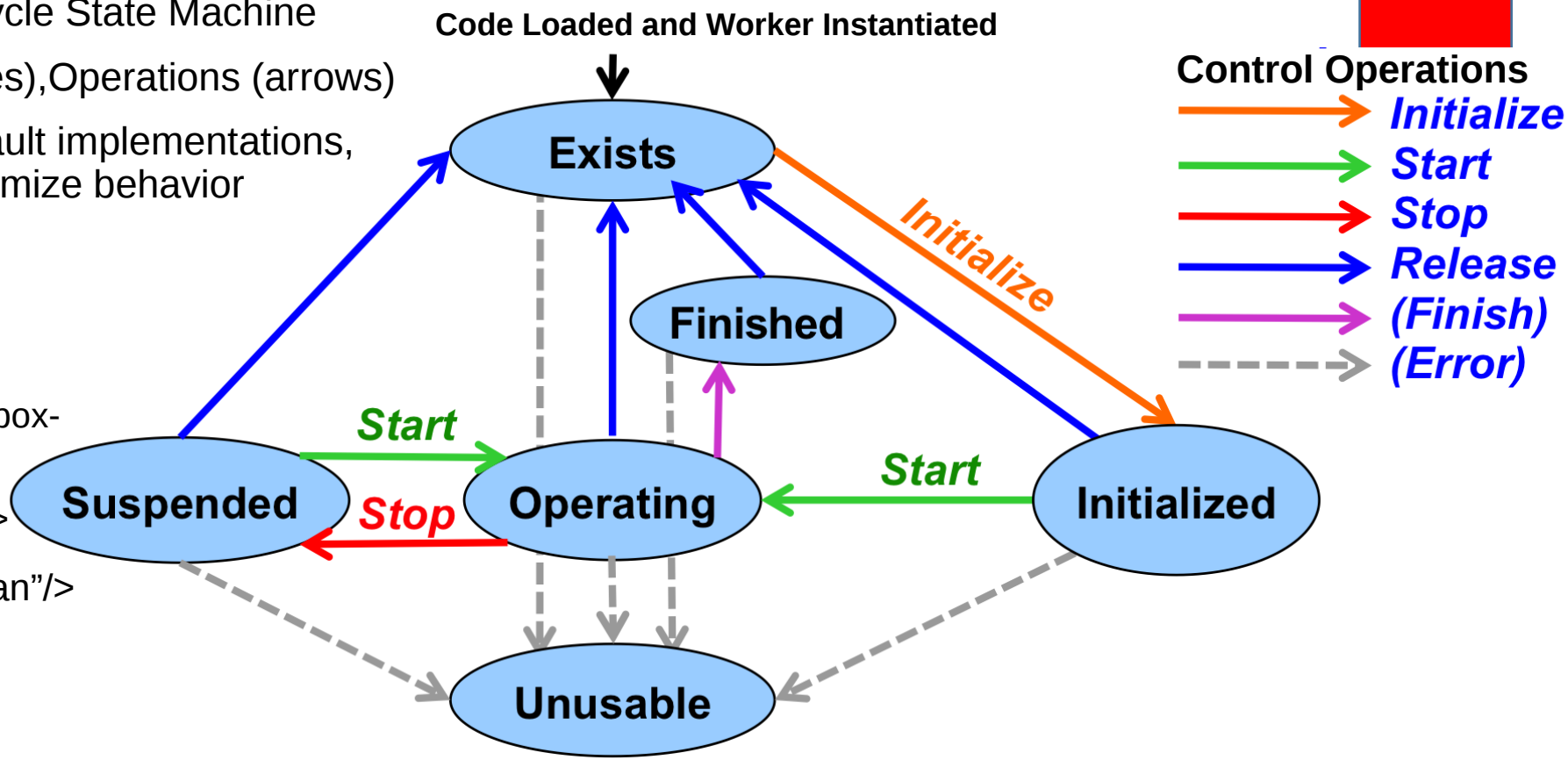


- Control Software launches and controls the Workers at run-time in an Application. It can be the trivial “ocpirun” utility, or a full-fledged Python or C++ application using the Application Control Interface (ACI)
- Control Software sees uniform view of how to control workers, each Authoring Model defines how this is accomplished from the point-of-view of the worker itself, by defining two key aspects of control:
  - LifeCycle Control
    - Fixed set of control operations available to every worker
  - Configuration Property Access
    - Logically, the knobs and meters of the worker's “control panel”
- Control Plane encompasses how the Control Software can access LifeCycle Control and Configuration Property Access of Workers at run-time in an Application

Control Plane - LifeCycle Control



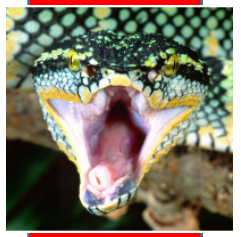
- LifeCycle Control
  - Standardized for *all* Authoring Models and mostly managed by the framework
  - Defined by the LifeCycle State Machine
  - Control: States (circles),Operations (arrows)
  - Operations have default implementations, but Worker can customize behavior



…/worker1.rcc/worker1.xml:

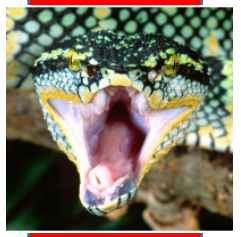
```
<RccWorker language='c++' spec=boombox-spec
controlOperations=”initialize,release”>
  <Property Name=“next” Type=“Boolean”/>
</RccWorker>
```

Control Plane - Configuration Properties



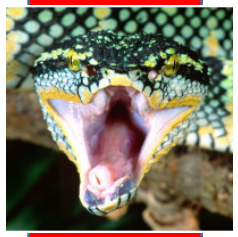
- Enable control and monitoring of Workers by Control Software
  - Memory Map registers
- Specified in OCS and OWD <Property Name="next" Type="Boolean"/>
  - OCS properties available to all of its implementations (Workers)
  - OCS properties may be augmented in OWD (<specproperty>)
- Defined by Data Type and Read/Write Accessibility

Configuration Property - Accessibility Rules



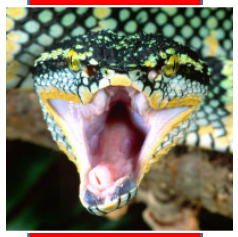
- Accessibility is from the perspective of the Control Software
- Can be *Volatile* (implies the framework *cannot* cache values)
  - *Volatile* property values are updated by “user code” within Worker
  - By default, all values are cached unless explicitly volatile
- Either *Writable* or *Initial*, but **NOT** both
  - *Writable* property values settable at run-time
  - *Initial* property values set at initialization-time, not run-time
- *Default* assignment is **ONLY** allowed with *Writable* or *Initial*
- OWD may **ADD** accessibility to OCS property
  - Cannot “unset” an OCS flag to make inherited properties *less* accessible
  - Use <SpecProperty> in the OWD to “add-to” a OCS property's configuration

Configuration Properties - Common Attributes



- Commonly used Attributes across many XMLs:
  - Name – case insensitive name of element
  - Type – data type of element
  - Default – specify default value according to Type attribute
  - Accessibility (Only OCS or OWD)
    - (None) – (*special* edge case; do not use)
    - Volatile – changeable by worker
    - Writable – can be written from the Control Software
    - Initial – set an initial value prior to Worker entering operating state, and never again
    - Readable – (*special* HDL-only edge case; do not use)
    - Parameter
      - Two use cases

Configuration Properties - Parameter Attribute



- TWO use cases:

  1) "Convenience variable" for defining **Build-time** constants in other Property Attributes like stringlength, sequencelength, arraydimensions or default
     - Supported in both OCS and OWD

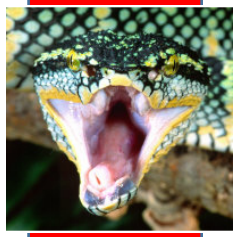
       <Property Name="myProp1" Default="16" Parameter="true"/>

       <Property Name="myProp2" Type="short" SequenceLength="myProp1*2-1"/>

  2) **Build-time** constants to create different configurations of same Worker which trade-off performance and resource utilization
     - C++ ⇨ **static const** and VHDL ⇨ **generic**
     - At run-time, Control Software matches OAS with pre-built artifacts

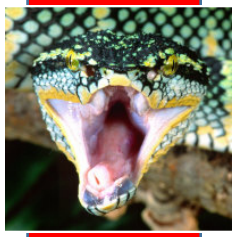
- Parameter attribute is **NOT** allowed for properties declared as *Writable*

Configuration Properties – Types (Scalar)



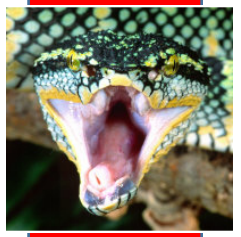
- Default type is uLong
- Unsigned types: uChar, uShort, uLong, uLongLong
- Signed type: short, long, longLong
- char
  - Unit of a string
  - Signed decimal value [-128, 127]
  - unsigned decimal value [0, 255]
- float, double, bool
- String
  - Use StringLength to specify max length of string excluding null termination
- Enum
  - Use Enums to specify a comma separated list of strings

Configuration Properties – Types (Structure)



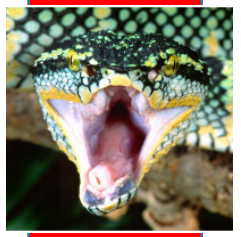
- Struct
  - Use Member elements to specify Name and Type
- Sequences & Arrays
  - Use SequenceLength or ArrayDimensions to define a type that is a Sequence or Array (Standard or Multidimensional)

Configuration Properties – Types



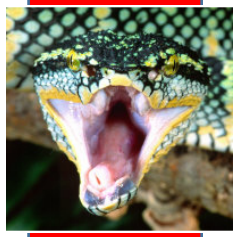
- Scalars
  - Unit length of 1
- Sequences
  - Variable length
  - *SequenceLength* defines the maximum length of a Sequence (ex: user input)
- Arrays
  - Fixed length
  - *ArrayDimensions* defines the fixed-length of an Array (ex: filter taps in a FIR filter)
- **CAN**: have a Sequence of Arrays
- **CANNOT**: have an Array of Sequences or Sequence of Sequences
- For an Array of Arrays use *ArrayDimensions* to infer multidimensionals

Configuration Properties – Examples



- Scalar Example
  - **<Property Name="myScalar" Type="short"/>**
  - myScalar is a Scalar of 1 signed 16-bit value
- Sequence Example
  - **<Property Name="mySequence" Type="uLong" SequenceLength="64"/>**
  - mySequence is a Sequence from 0 to 64 unsigned 32-bit values
- Array Example
  - **<Property Name="myArray" Type="longLong" ArrayDimensions="32"/>**
  - myArray is an Array of 32 signed 64-bit values; never more nor less
- Array of Array Example
  - **<Property Name='myArrayOArrays' ArrayDimensions="16, 32, 64" Type="short"/>**
  - myArrayOArrays is three Arrays, containing Arrays of lengths 16, 32, and 64, containing signed 16-bit values, for a total of 16+32+64=112 16-bit values

Port

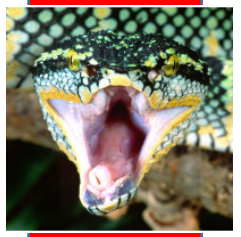


- Input or Output data interfaces of a Component
  - Uniquely named
  - Unidirectional (Consumer or Producer)
  - With or Without a Protocol (DISCUSSED ON NEXT SLIDE)
- *Port* is an Element of the OCS having several Attributes:
  - *Name*
    - Must be unique, case insensitive and valid across different languages
  - *Producer*
    - Unidirectional (Consumer or Producer)
    - Consumer: **(default)** *Producer* attribute is "*false"* or not defined
    - Producer: *Producer* attribute is "*true"*
  - *Protocol* (Permissive or declares protocol)
    - Permissive when protocol is not assigned, *i.e.* accepts any protocol! (*e.g.* file_write.rcc/.hdl)
      - 256 operations (opcodes) or message types
      - Messages are of unbounded size, up to 64KB
      - Messages may be of Zero-Length
      - Granularity of messages is a Single Byte
    - Value of the attribute is the name of the protocol XML (.xml suffix is assumed if not present)
  - *Optional*
    - Indicates that Port may be left unconnected in an application

specs/boombox-spec.xml:

```
<ComponentSpec>
  <Port Name="ant" Producer="false" Protocol="rx-prot"/>
  <Port Name="speaker" Producer="true" Protocol="audio-prot"/>
  <Property Name="display" Type="float" Volatile="true"/>
  <Property Name="dial" Type="float" Writable="true"/>
</ComponentSpec>
```

Protocol

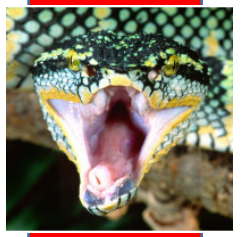


- Set of messages that may flow between Ports of Components
  - “shared” data path (pipelined)
- Messages are specified by:
  - Operation Code: message type encapsulating zero or more Operation Arguments
  - Operation Argument: payload data of the Operation Code
- Ports connected between Components MUST:
  - have matching protocols OR
  - be Permissive (Worker must “know” structure of data within message)
- Described by one or more OpenCPI Protocol Specification (OPS) XML files
  - With ***-prot.xml** suffix. (Deprecated: *_prot.xml, *-protocol.xml, and *_protocol.xml)

Protocol: OPS XML

../specs/audio-prot.xml:

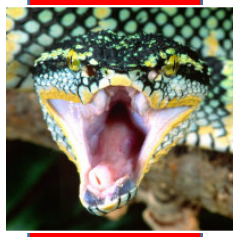
```
<Protocol>
  <Operation Name=“freq”>
    <Argument Name=“high_low”
type=”struct” SequenceLength=”2048”/>
      <Member Name=“high” type=”short”/>
      <Member Name=“low” type=”short”/>
    </Argument>
  </Operation>
</Protocol>
```



- *Protocol* – define Top-level Attributes
  - Used to override valued inferred by the Operations, or in the absence of Operations
  - NumberofOpcodes, DataValueWidth, DataValueGranularity, ZeroLengthMessages, MaxMessageValues,etc.
- *Operation* – message type or “Opcode”
- *Argument* – data field in a message payload for the given *Operation*
  - Same Attributes as Configuration Property: Name, Type, ulong, SequenceLength, etc
  - If not defined for an Operation, its messages have no data fields, i.e. Zero-Length Message
- *Member*
  - **ONLY** used when *Argument* is of Type Struct
  - Define the Name and Type of each *Member*

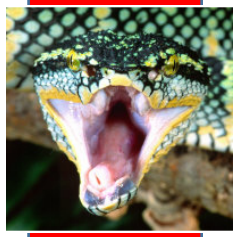
Example of a Protocol available within OpenCPI:

`<core-project>/specs/TimeStamped_IQ-prot.xml`



```
<Protocol>
  <Operation name="samples" >
    <Argument name="iq" type="Struct" SequenceLength="4092">
      <Member name="I" type="Short"/>
      <Member name="Q" type="Short"/>
    </Argument>
  </Operation>
  <Operation name="time">
    <Argument name="sec" type="ulong"/>
    <Argument name="fract_sec" type="ulong"/>
  </Operation>
  <Operation name="interval">
    <Argument name="delta_time" type="ulonglong"/>
  </Operation>
  <Operation name="flush"/>
  <Operation name="sync"/>
  <Operation name="done" />
</Protocol>
```

App Worker Development Flow



1) OPS: Use pre-existing or create new
2) OCS: Use pre-existing or create new
3) Create new App Worker (Modify OWD, Makefile, and source HDL/RCC code)
4) Build the App Worker for target device(s)
5) Create Unit Test ({component}-test.xml, generate, verify and view scripts)
6) Build Unit Test
7) Run Unit Test