The Waveform Description Language

Moving from Implementation to Specification in Ptolemy II

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Overview

The system specification problem
better implementations
Waveform Description Language solutions
Comparison of WDL and Ptolemy characteristics
WDL as an abstract Ptolemy domain
Summary

UK Programmable Digital Radio (PDR) Phase 1,
Waveform Description Language (WDL) programme
(DERA contract CU009-0000002745)

Raytheon, Communication Systems Division, Fort Wayne, Indiana,
Racal, Racal Research Limited, England

The system specification problem

Complex systems are

- costly
- late
- mis-functional
- inflexible

Complex system specifications are

- large
- ambiguous
- contradictory

Complete specification (High Level)

System specifications - very challenging

- large, unreadable

Informal specification

- terse - omissions lead to ambiguities
- verbose - duplications lead to contradictions

Formal specification

- good in principle
- impractical for real applications
- unapproachable for most practitioners

WDL

- pragmatic compromise
  - formalisable, modular, familiar, practical, acceptable

The system implementation problem

Implementation practices do not support re-use

- porting - old code on new platform
- copying - old code in new context
- sharing - pre-written generic code

Re-use

- code already written
- bugs already removed

- requires a well defined functionality
- inhibited by implementation details

‘Lego’ Bricks

Software Defined Radio - JTRS

- assemble arbitrary waveform from pre-defined library blocks
  - waveform == radio protocol
- new waveforms incur minimal costs and delays

UK Programmable Digital Radio (phase 1)

- script for assembling ‘Lego’ bricks
- identify the ‘Lego’ bricks and their parameters

System defined by composition of sub-systems

- composition rules must be defined
- subsystem behaviour must be defined

Need a meaningful specification - WDL

Specification not Implementation

Implementation - how it can be done

Full of non-portable constraints

Specification - what must be done

Ignore all the inconvenient details

Modern tools support an increasingly generalised implementation

Ptolemy better than most

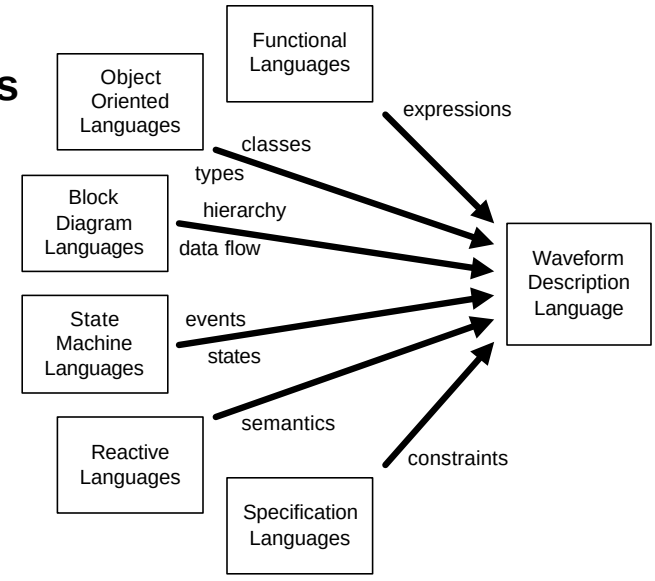
Ptolemy also an implementation

WDL abstracts Ptolemy to a specification

WDL Antecedents

Implementation practices re-applied in the specification domain

message flow diagrams
state machines



Comparison of WDL and Ptolemy

Ptolemy

- simulates a generalised implementation
- cross code-generates the same implementation

WDL more abstract than Ptolemy

- defines an abstract specification
  - refines to simulate a reference model
  - refines further to generate a production implementation
- more abstract scheduling
- more abstract type system
- more abstract leaf specification

Scheduling Abstraction

Ptolemy scheduling - one domain per diagram

- uniform policy is convenient
- uniform policy is restrictive
- chosen policy is restrictive
- each domain is a scheduling implementation

Ptolemy does not support

- input as Continuous Time
- overflow as Discrete Event
- samples as Synchronous Data Flow

WDL Flow Types

Ptolemy - one domain per diagram

BDF, CT, DDF, DE, DT, HDF, PN, SDF, SR, ...

WDL - one flow type per message path

event - (Synchronous Reactive semantics - one at a time - OR)
token - (Data Flow semantics - all at once - AND)
value - (asynchronous - breaks sender/receiver coherence)
signal - ('continuous flow' - CT or SDF)

WDL does support

input as a signal flow
overflow as an event flow
samples as a token flow

WDL Flow Deductions

Ptolemy

domain restricts an implementation

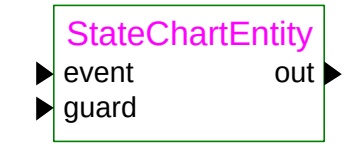
WDL

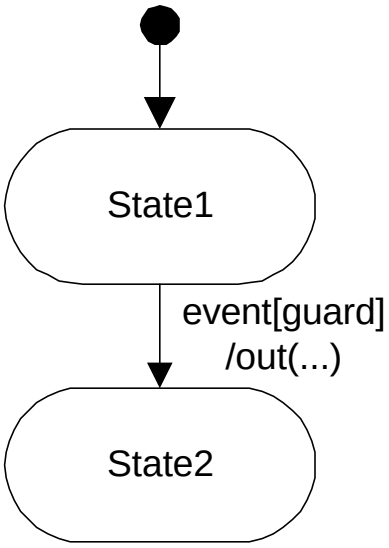
flows specify a behaviour

WDL is an abstract specification domain

translator to specific implementation domains
- regions of consistent flow
- smart policies for region boundaries
- automatically exploits the EvenBetterDataFlow domain

(UML) Statechart



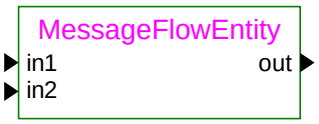


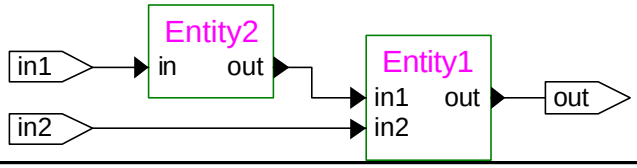
State1 OR State2

WDL 'extension' to UML:

state behaviour may be a message flow

Message Flow Diagram





Entity1 AND Entity2

WDL Message Flow Diagram

each arc has defined data and flow type, connecting at ports

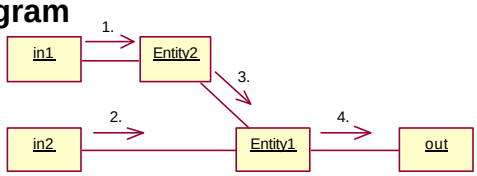
each entity is self-scheduling - rendezvous of relevant ports

external ports to define hierarchy

UML Comparison

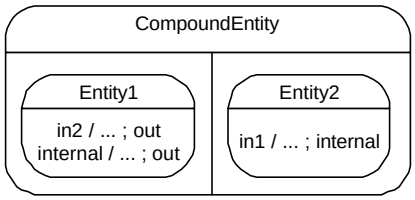
UML Collaboration Diagram

- no hierarchical ports
- no arc semantics
- no multi-input handling
- external scheduling



UML Concurrent State Machine

- 'solid' AND semantics
- no hierarchical ports
- arcs connect by name
- no multi-input handling



CORBA Components

Extension of Object Oriented Concepts

Objects can provide data encapsulation
Object provide no synchronisation

Components add synchronisation

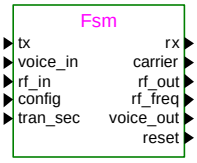
Components remove hierarchy

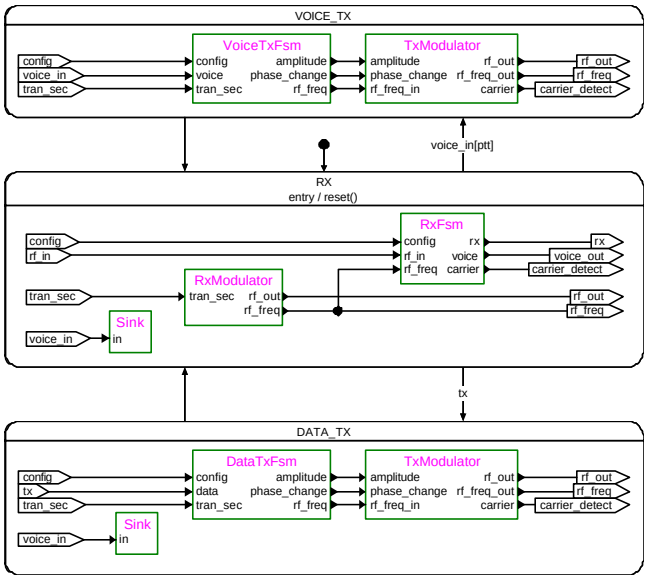
- just two scales
  - outside component - disciplined
  - inside component - anarchic

WDL Entities add synchronisation

WDL Entities support hierarchy

Example State Machine





Constructed Type Abstraction

Simplistic systems

- `double` and may be `int` too
- array is a sequential accident

Useful systems

- record and array type constructors

Ptolemy deduces type from values

WDL deduces or declares types

WDL has discriminated union as well

- record expresses AND of fields within a message
- union expresses OR of alternate messages
- discriminated union ensures type safety

Bit-true Type Abstraction

Simplistic systems

just `int`

Implementation perspective

`octet` or `char`

`fix<13,5>`

Specification perspective

any type with at least 40 dB dynamic range

WDL defines minimum requirements of types

translator selects/synthesises implementation type

Bit-true Type Overlay

Implementation approach

embed bit-true declarations

But: a re-use may require a different bit-truth

Specification approach

A bit-true layout is overlaid onto abstract type

A pattern matching layin construct supports type discovery

Leaf Behaviour Abstraction

Ptolemy Classic

- one template per actor per domain per target
- template per domain led to domain inconsistencies
  - SDF without corresponding CGC support

Ptolemy II

- one (Pt)Java template per actor (simulation)
- one template per language per AST node (code generation)

(Pt)Java is not a specification language

Precision is implemented not specified

- ok for 32 bit RISC
- bad for 24 bit DSP
- really bad for FPGA

Statement scheduling is sequential not parallel

- ok for single CPU
- bad for FPGA

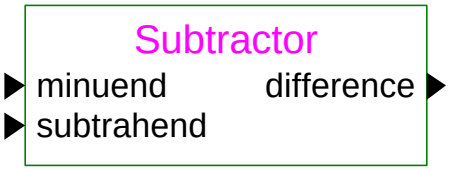
Code is over-specified

- loop counters must be analysed away

Overloading is limited

- C++ better but not a solution

WDL leaf specification




```
entity Subtractor
{
  in minuend;
  in subtrahend;
  out difference;
  response minuend subtrahend            // Whenever a rendezvous of
  {                                      // minuend and subtrahend exists
    specification
    {                                    // receive minuend and subtrahend
      difference(minuend - subtrahend);  // subtract values
    };                                   // send to difference
  };
};
```

Polymorphic

type, shape, flow, language

Specification in WDL

Progressive decomposition

systems - subsystems - components - building blocks

Single hierarchical perspective

clear readable specification

removes ambiguities, avoids contradictions

Implementation in WDL

Progressive refinement of specification

further decomposition

practical constraints

recomposition

Minimal refinement

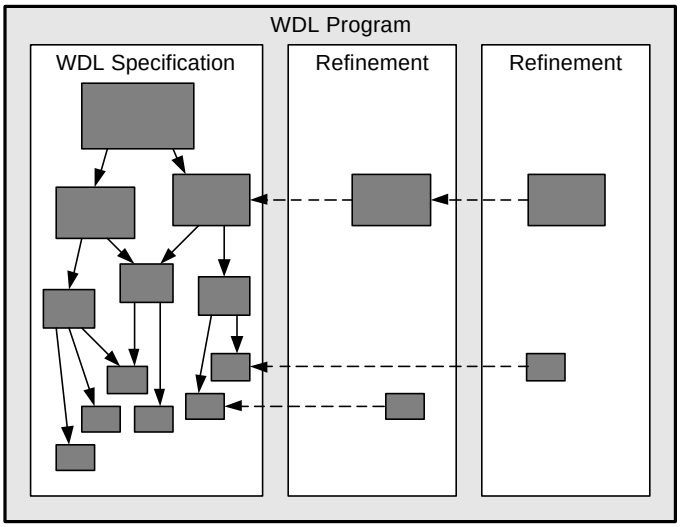
executable reference model

WDL Refinement

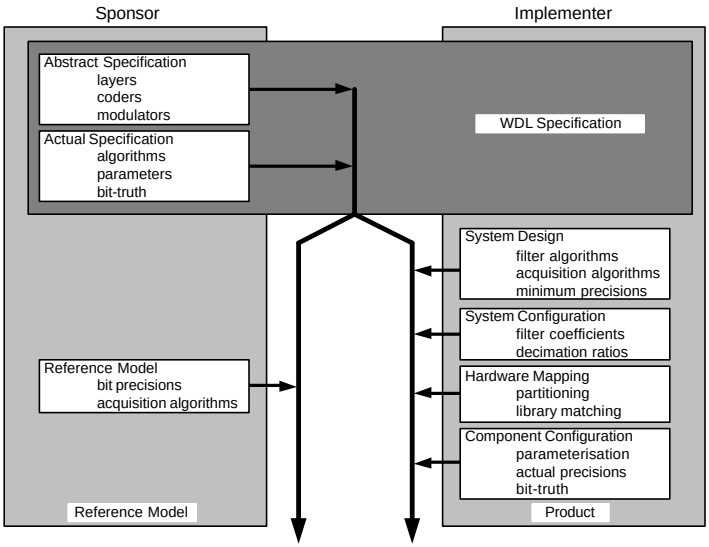
Progressive decomposition

Progressive refinement

Specification preserved



WDL Refinement



Realising WDL

Reuse/adapt COTS
- Ptolemy II most appropriate

Original perception
- WDL-specific Vergil extensions
  - WDL to Ptolemy translator embedded in Vergil

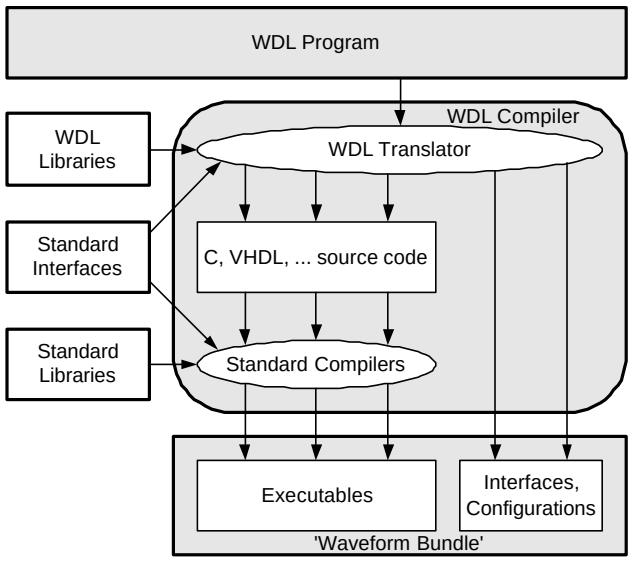
Simpler perception
- WDL is just a new abstract domain
  - translates itself to other domains
- WDL-enabling Vergil extensions
  - Port/Parameter configuration form
  - UML statechart
  - Nested flow chart

WDL Compilation

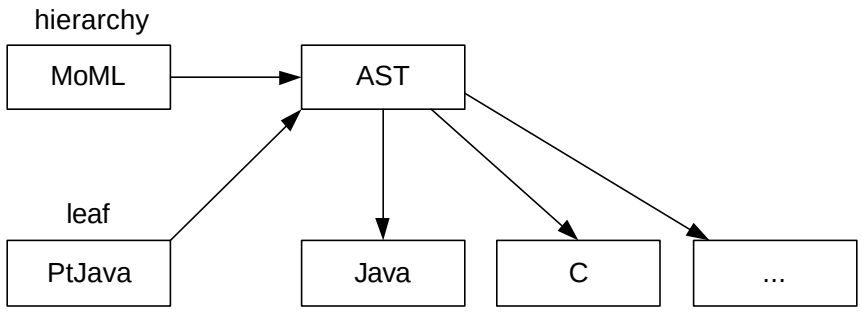
WDL libraries
re-use

Standard interfaces
bit truth

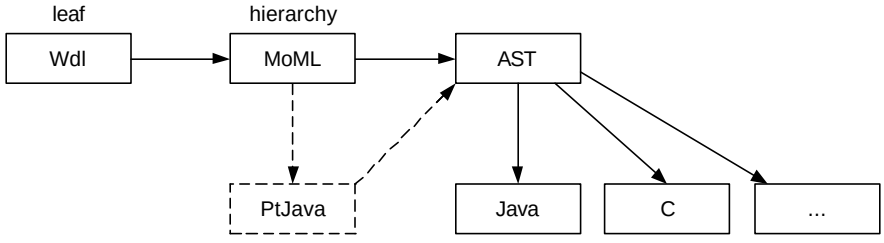
Standard libraries
pre-existing code



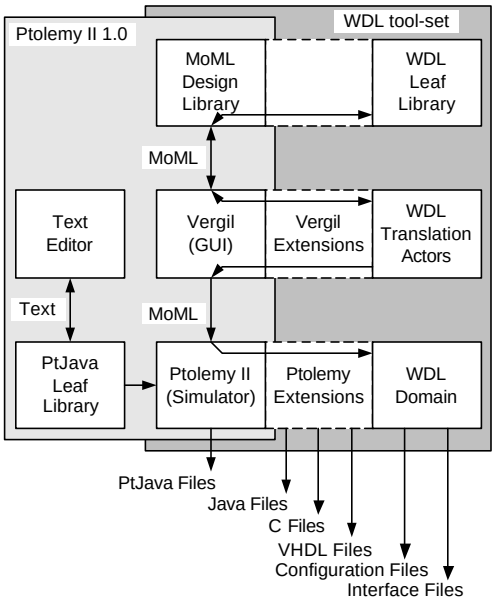
Ptolemy II Translations



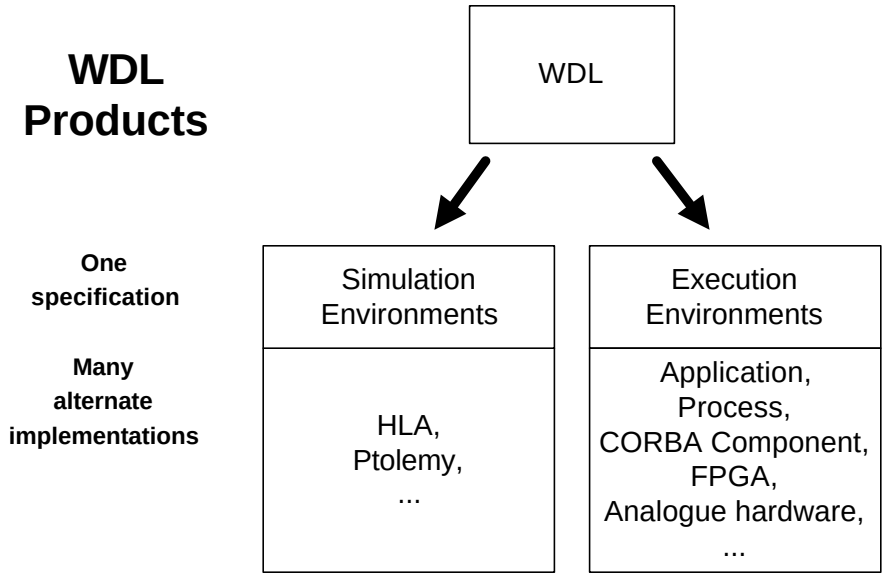
WDL Translations



Ptolemy extension for WDL



WDL Products



New programming paradigm

Only specification
- eliminates the implementation problems
- refinable to any target

Behavioural parameterisation
- inner behaviour passed in from outside
- dead specification elimination

Parallel computing
- entity/actor parallelism
- array parallelism

Re-use at last

Real or bogus panacea?

Status

Phase 1 (4 months: December 1999 to April 2000)
- Initial consideration of language concepts
- Example decomposition of FM3TR (1 month)
  - clearer, many anomalies reported back

Phase 2 (2 years: April 2001 to April 2003)
- Preliminary Editor - October 2001
- Preliminary Simulator - April 2002
- Preliminary Code Generator - October 2002
- Open source, IPR free on web.

Summary of Language

WDL specifies a determinate behaviour
Decomposition with single perspective

Refinement to a reference model
Refinement to product implementations

Polymorphism to exploit generic libraries
Realistic scheduling models
Type-oriented code generation for flexibility

Free

Summary of Comparison

Ptolemy Classic - most powerful/versatile (fast)
Ptolemy II - most powerful/versatile (flexible)
Ptolemy encourages implementation perspective
domains, exact types, (Pt)Java leaves
WDL (domain) abstracts to a specification
flows, constrained types, constraint language
WDL refines specification to an implementation
refinement to reference model part of a specification

Summary of Goals

WDL is an open program

collaboration welcome and needed

? industry standard via SDR Forum and OMG ?

Better quality specifications

sponsor provides reference model

Semi-automated code generation

months rather than years