MARTe Tutorial

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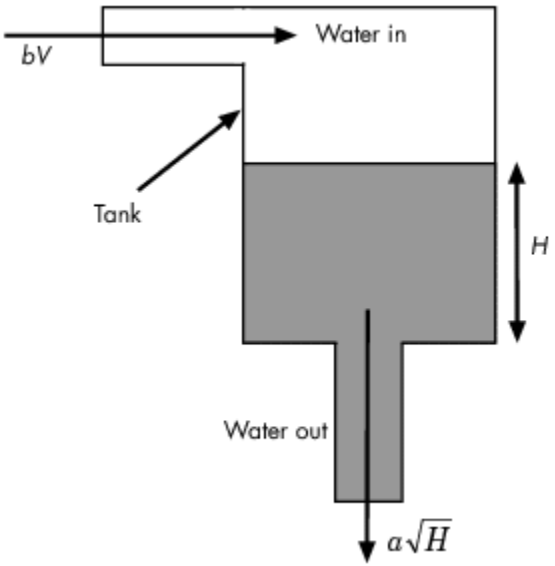
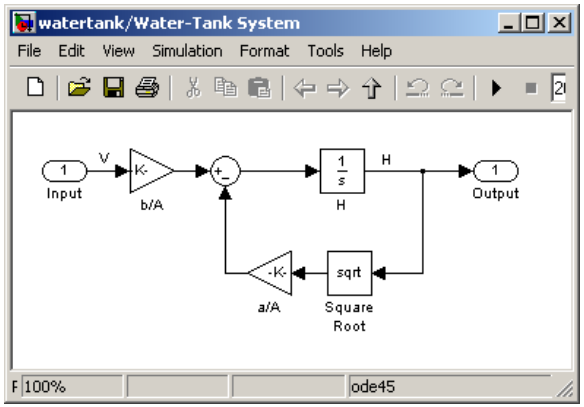
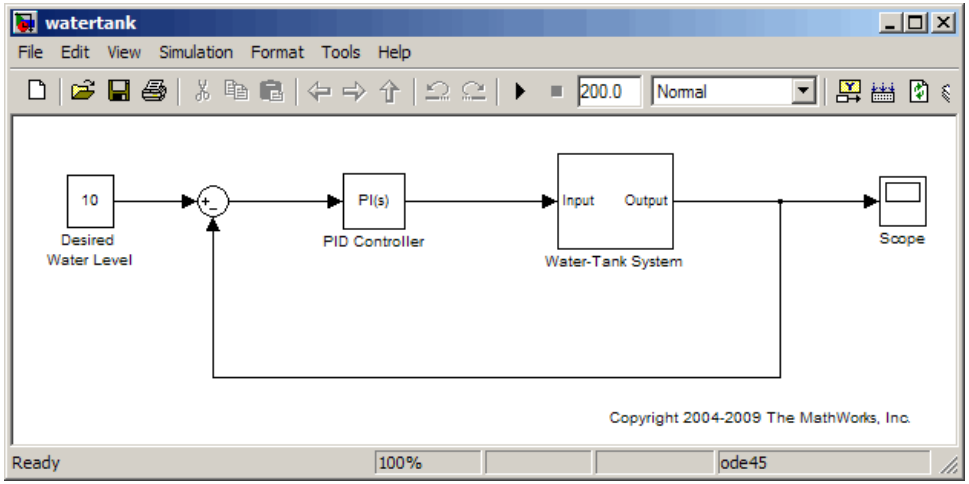
The water tank



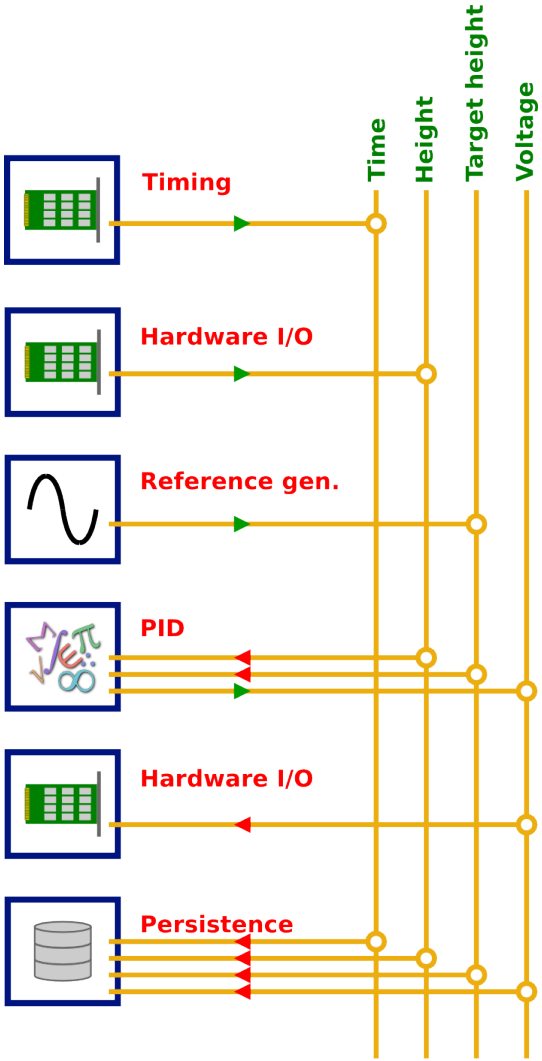
$$\frac{d}{dt}Vol = A\frac{dH}{dt} = bV - a\sqrt{H}$$

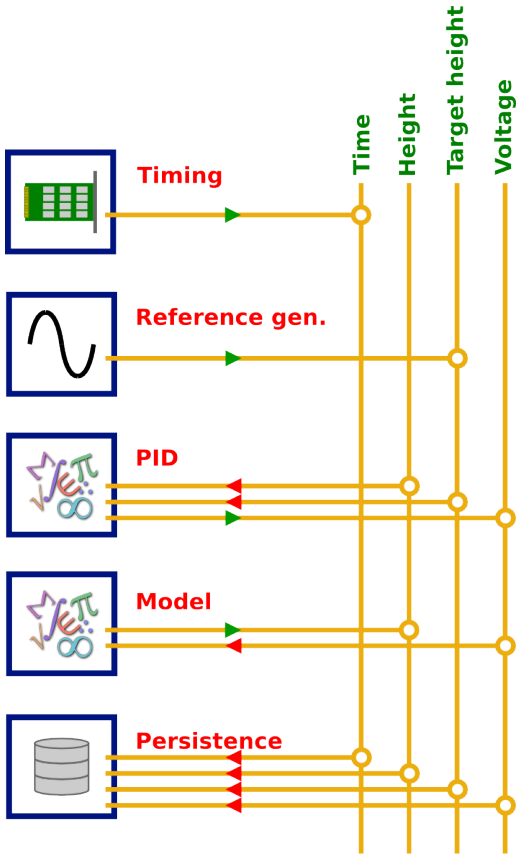




- Vol – volume of water in tank
- A – cross-sectional area of water in tank
- b – constant related to flow rate into the tank
- a – constant related to flow rate out of the tank
- H – height of water

What GAMs for the water tank?

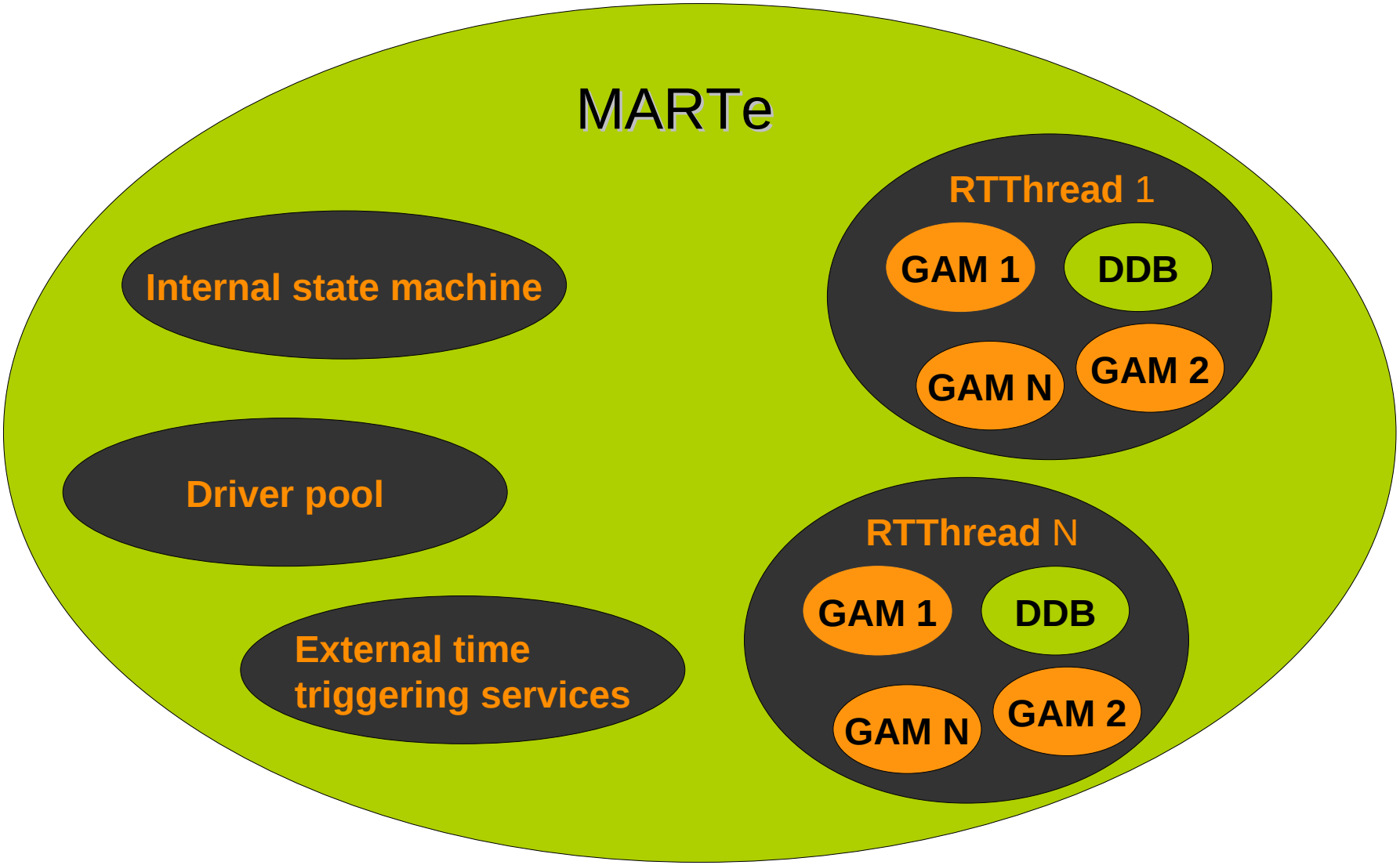




Development cycle

- What are my needs?
  - Interfaces to hardware
  - Algorithm execution
  - Plant simulation
  - Connection between components (DDB)
  - Interfaces to outside world
- What do I have ready to be used?
  - Recycle hardware interfaces
  - Reuse algorithms

MARTe World


MARTe
Internal state machine
Driver pool
External time triggering services
RTThread 1
GAM 1
DDB
GAM N
GAM 2
RTThread N
GAM 1
DDB
GAM N
GAM 2

Requirements for our goal

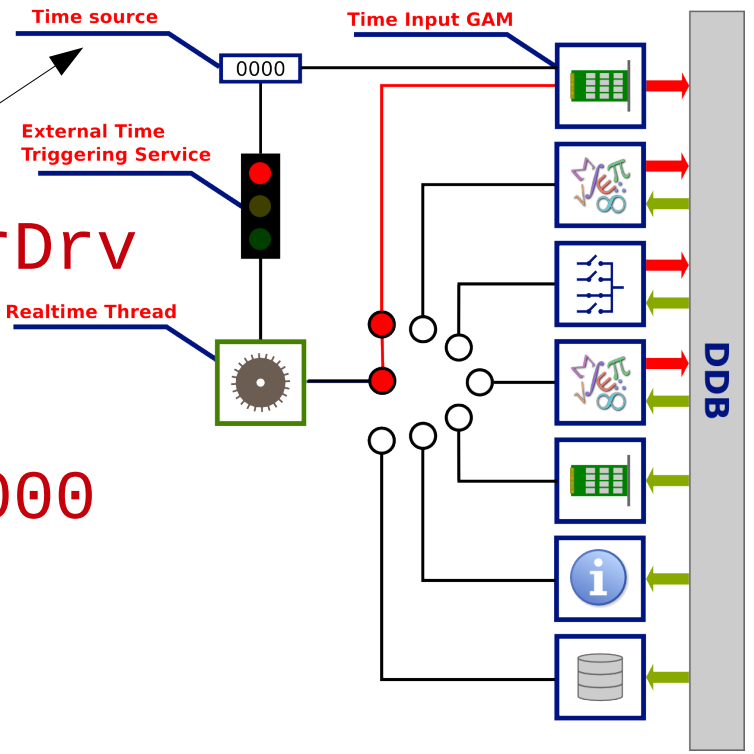
- Development of a water tank simulator
  - Time provider (timer)
  - Reference generation
  - A GAM with the model of the plant
    - water tank
    - pump power supply
  - PID
  - Data downloading
  - External triggering of the state machine

Skeleton configuration file

```
+MARTe = {
   Class = MARTeContainer
   StateMachineName = StateMachine
   MenuContainerName = MARTe
   +DriverPool = {...}
   +Messages = {...}
   +ExternalTimeTriggeringService = {...}
   +Thread_1 = {...}
}
```

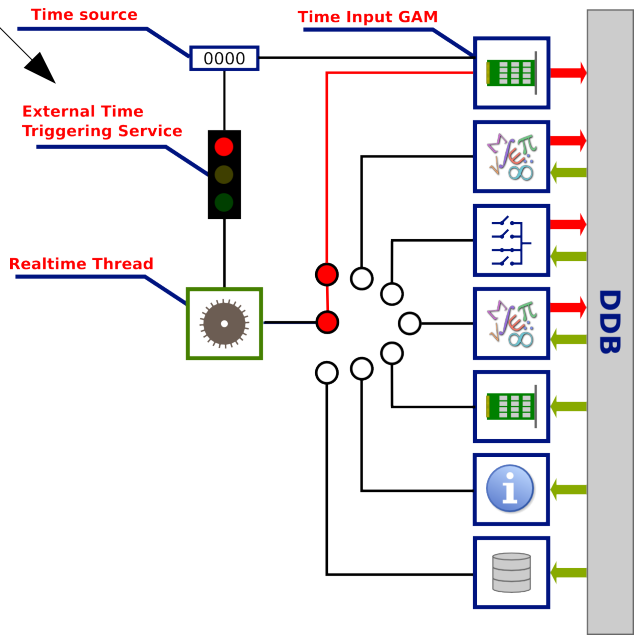
Generic Timer

```
+MARTe = {
   ...
   +DriverPool = {
      +TimerBoard = {
         Class = GenericTimerDrv
         NumberOfInputs = 2
         NumberOfOutputs = 0
         TimerUsecPeriod = 1000
      }
   }
   ...
}
```



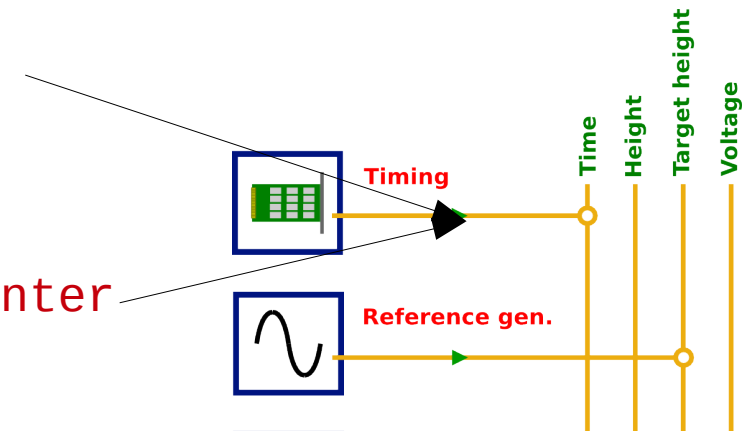
External Time & Trigger

```
+MARTe = {
   ...
   +ExternalTimeTriggeringService = {
      Class = InterruptDrivenTTS
      TsOnlineUsecPeriod = 1000
      TsOnlineUsecPhase = 0
      TsOfflineUsecPeriod = 10000
      TsOfflineUsecPhase = 0
      TimeModule = {
         BoardName = TimerBoard
      }
   }
   ...
}
```



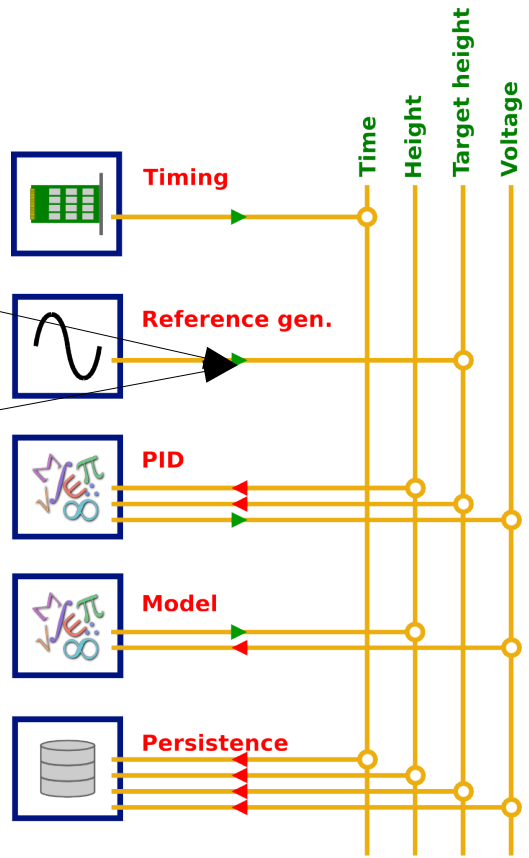
IOGAM (Timer)

```
+Thread_1 = {
    ...
    +Timer = {
        Class = IOGAMs::TimeInputGAM
        TriggeringServiceName = ExternalTimeTriggeringService
        BoardName = TimerBoard
        Signals = {
            time = {
                SignalName = usecTime
                SignalType = int32
            }
            counter = {
                SignalName = timerCounter
                SignalType = int32
            }
        }
    }
    ...
}
```



Reference Generator

```
+Thread_1 = {
    ...
    +WaveformGen = {
        Class = WaveformGenerator
        UsecTime = usecTime
        +waterHeightReference = {
            Class = WaveformClassSine
            Frequency = 0.1
            Gain = 1
            Offset = 2.5
        }
        +zeroSignal = {
            Class = WaveformClassPoints
            TimeVector = {0 1}
            ValueVector = {0 0}
            Frequency = 1
        }
    }
    ...
}
```



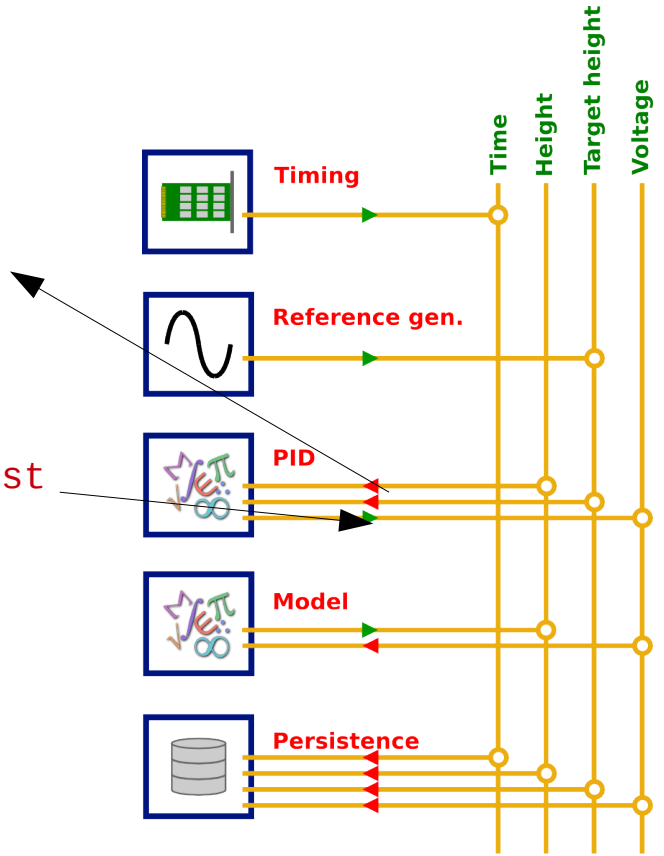
PID GAM (1)

```
+Thread_1 = {
    ...
    +PIDGAM = {
        Class = PIDGAM
        TStart = 0.0
        TEnd = 10000.0
        InputSignals = {
            PIDInput = {
                SignalName = PIDIn
                SignalType = PIDGAMInputStructure
                FlatNamed = True
            }
        }
        OutputSignals = {
            PIDOutput = {
                SignalName = PIDOut
                SignalType = PIDGAMOutputStructure
                FlatNamed = True
            }
        }
        ...
```

```
struct PIDGAMInputStructure {
    /** Time signal */
    int32                       usecTime;
    /** Reference signal to be      followed */
    float                       reference;
    /** Measurement signal */
    float                       measurement;
    /** Feedforward control */
    float                       feedforward;
};
```

PID GAM (2)

```
+Thread_1 = {
    +PIDGAM = {
        ...
        Remappings = {
            InputInterface = {
                usecTime = usecTime
                reference = waterHeightReference
                measurament = waterHeight
                feedforward = zeroSignal
            }
            OutputInterface = {
                controlSignal = pumpVoltageRequest
                feedback = pumpVoltageRequest
                error = pidHeightError
                integratorState = pidIntState
            }
        }
        Kp = 3.00
        Ki = 2.00
        Kd = 0.20
        SamplingTime = 0.001
        ControllerOn = On
    }
    ...
```



Water Tank model

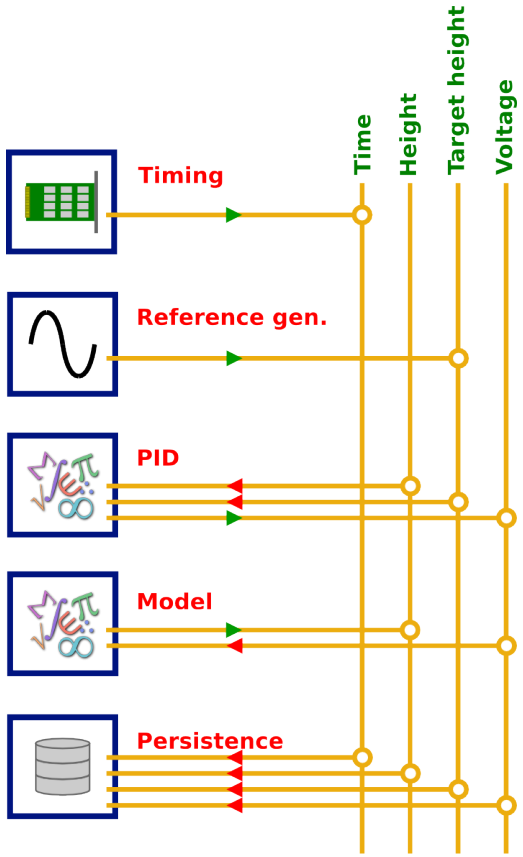
- Only GAM not readily available
- GAM development cycle
  - Design algorithm
    - Piece of paper
    - Software (matlab, octave, ...)
  - Decide inputs and outputs
  - What parameters are configurable?
    - What parameters are compulsory?

Water Tank variables

```
class WaterTank : public GAM, public HttpInterface {
...
// Parameters
private:
    /** Last usec time (for the integral) */
    int32                                       lastUsecTime;
    /** Last water height (for the integral) */
    float                                       lastHeight;
    /** Last voltage value after saturation*/
    float                                       lastVoltage;
    /** The input flow rate constant*/
    float                                       bFlowRate;
    /** The output flow rate constant */
    float                                       aFlowRate;
    /** Tank area */
    float                                       tankArea;
    /** Maximum voltage that can be requested */
    float                                       maxVoltage;
...
};
```

What input/output signals?

- Input
  - Time
  - Requested voltage from PID
- Output
  - Water height



Water Tank read config.

```
bool WaterTank::Initialise(ConfigurationDataBase& cdbData) {
    if(!AddInputInterface(input,"InputInterface")){
            AssertErrorCondition(InitialisationError,
"WaterTank::Initialise: %s failed to add input interface", Name());
           return False;
        }
...
    if(!cdb->Move("InputSignals")){
                AssertErrorCondition(InitialisationError,
"WaterTank::Initialise: %s did not specify InputSignals entry", Name());
           return False;
    }
...
    if(!cdb.ReadFloat(aFlowRate, "aFlowRate", 20)){
            AssertErrorCondition(Information, "WaterTank %s::Initialise:
output flow rate not specified. Using default %f", Name(), aFlowRate);
        }
...
    if(!cdb.ReadFloat(tankArea, "TankArea", 20)){
            AssertErrorCondition(Information, "WaterTank %s::Initialise:
tank area not specified. Using default %f", Name(), aFlowRate);
        }
}
```

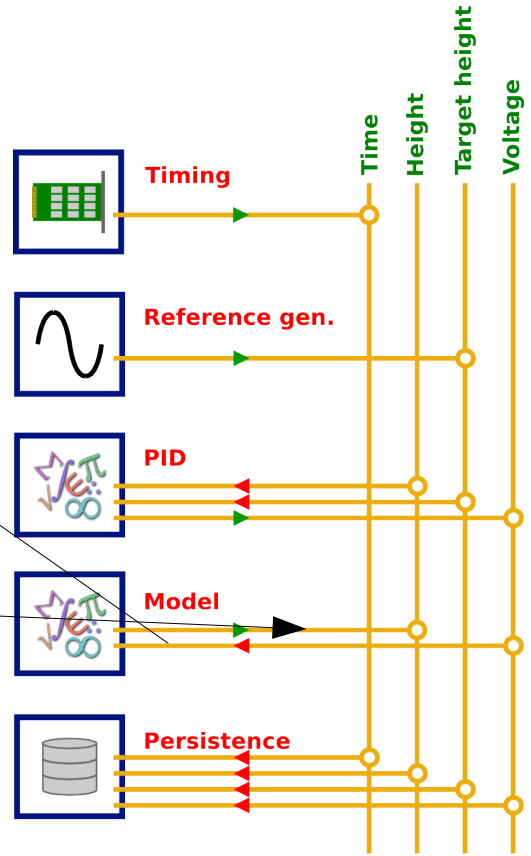
Input signals from DDB

Water Tank execution

```
bool WaterTank::Execute(GAM_FunctionNumbers functionNumber) {
    // Get input and output data pointers
    input->Read();
    int32 usecTime  = *((int32*)input->Buffer());
    float voltage       = ((float *)input->Buffer())[1];
    float *outputBuff = (float*)  output->Buffer();
    float height         = 0;
...
    //Saturate voltage
    if(voltage > maxVoltage){
                voltage = maxVoltage;
    }
    if(voltage < minVoltage){
                voltage = minVoltage;
    }
    //simple Euler method
    height   = (voltage * bFlowRate - aFlowRate * sqrt(lastHeight)) / tankArea
* (usecTime - lastUsecTime) * 1e-6 + lastHeight;
    lastHeight   = height;
...
    *outputBuff  = height;
...
    // Update the data output buffer
    output->Write();
}
```

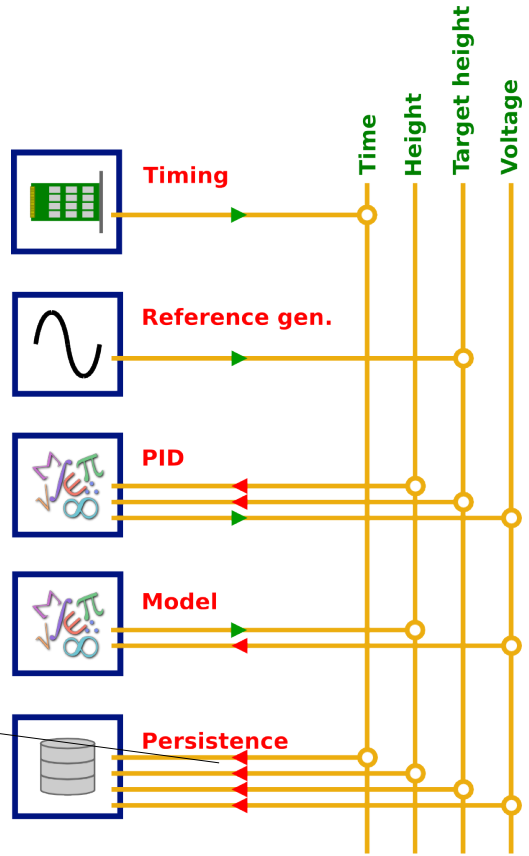
Water tank configuration

```
+Thread_1 = {
    +WaterTank = {
        Class = WaterTank
        InputSignals = {
            usecTime = {
                SignalName = usecTime
                SignalType = int32
            }
            voltage = {
                SignalName = pumpVoltageRequest
                SignalType = float
            }
        }
        OutputSignals = {
            height = {
                SignalName = waterHeight
                SignalType = float
            }
            pumpVoltage = {
                SignalName = pumpVoltage
                SignalType = float
            }
        }
        aFlowRate = 20.0
        TankArea = 20.0
        ...
```



Data collection

```
+Thread_1 = {
    ...
    +Collection = {
        Class = CollectionGAMs::DataCollectionGAM
        EventTrigger = {
            TimeWindow0 = {
                NOfSamples = 40000
                UsecPeriod = 250
            }
        }
        Signals = {
            CLOCK = {
                SignalName = usecTime
                JPFName = "TIME"
                SignalType = int32
            }
            WaterHeight = {
                SignalName = waterHeight
                JPFName = "WaterHeight"
                SignalType = float
            }
            ...
```



Plotting and Webstatistics

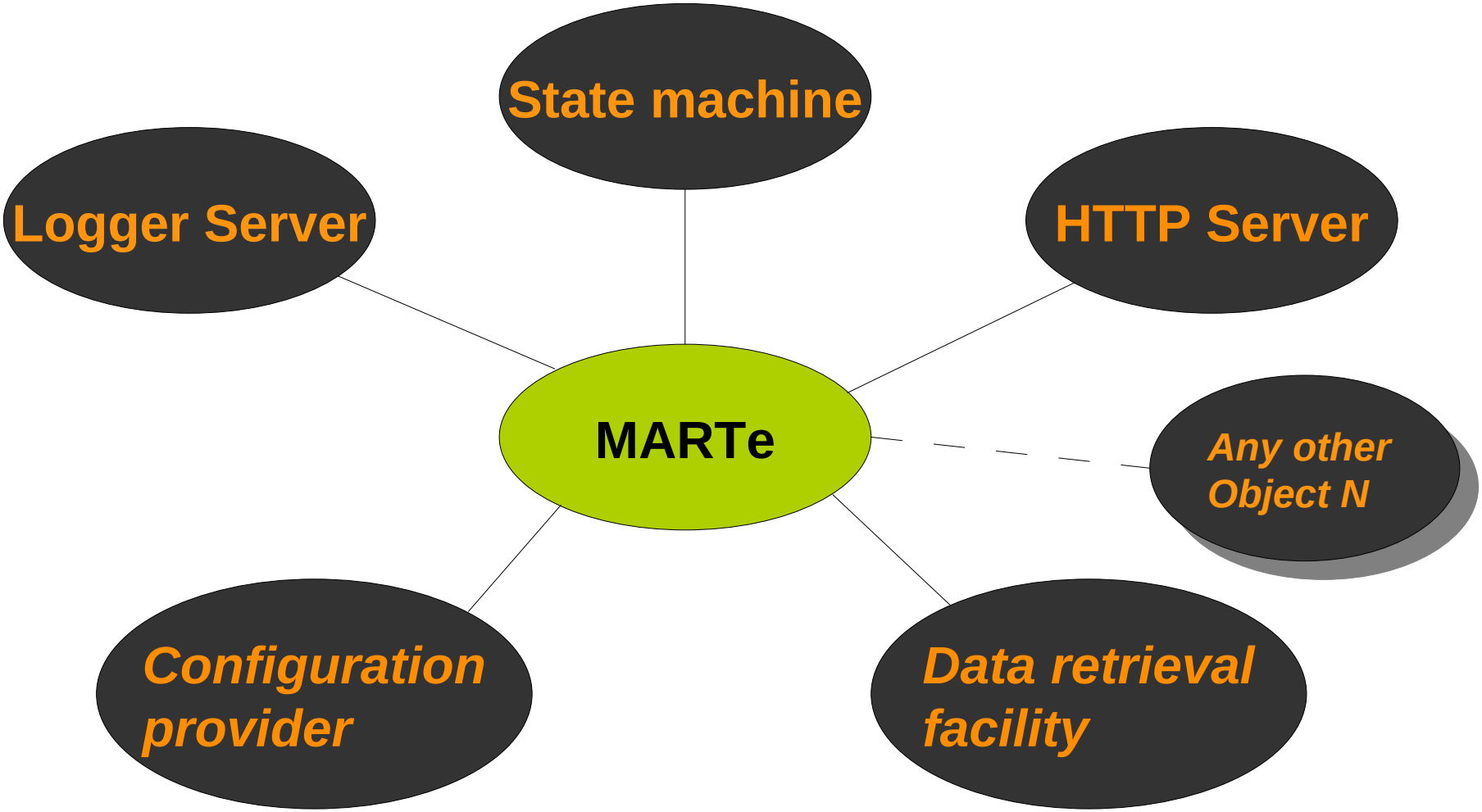
- GAMs readily available
- Display data using the HTTP interface
- Extremely useful to quickly debug and inspect signals in the DDB
- More information on the example slides

Execution order

- MARTe has two runtime cycles
- Online is associated with the real-time cycle, whereas offline is the stand-by mode
- GAMs can be Online *forever*

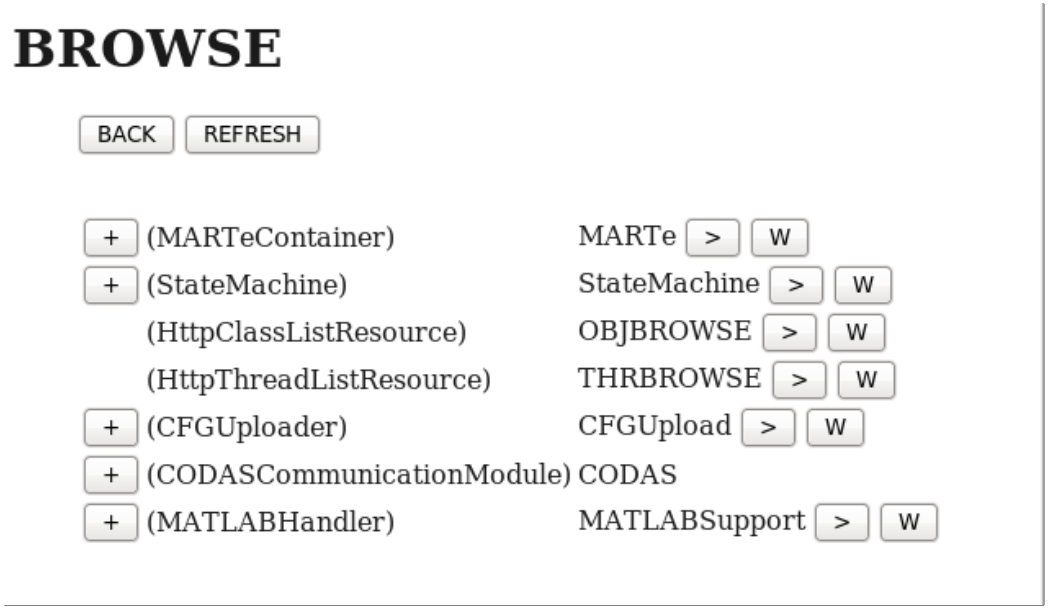

```
+Thread_1 = {
    ...
    Online = "Timer WaveformGen PIDGAM WaterTank
PlottingGAM Statistic Collection"
    Offline = "Timer PlottingGAM Statistic"
}
```

MARTe Universe



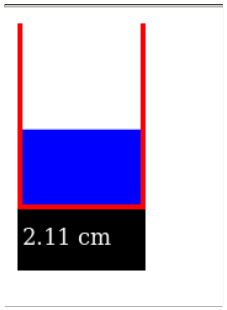
MARTe Universe components

```
LoggerAddress = localhost
DefaultCPUs = 8
+HTTPSERVER= {
     Class = HttpService
     Port = 8084
     Root = WEB
}
+WEB= {
     Class = HttpGroupResource
     +BROWSE = {
          Class = HttpGCRCBrowser
          Title = "Http Object
browser"
          AddReference = "MARTe
StateMachine OBJBROWSE THRBROWSE
CFGUpload MATLABSupport"
     }
}
+MATLABSupport = {
    Class = MATLABHandler
}
+CFGUpload = {
    Class = CFGUploader
}
+StateMachine = {
...
```



GAMs and HTTP interface

- GAMs may expose information about themselves using the HTTP interface
  - Write to a stream facility which is provided every time an HTTP request for their URL is performed



Time window n.	NumOfSamples	UsecPeriod	Start	End
0	40000	250	0	10000000

Total Samples = 40000

Total already read Samples = 39102

Current statistics:

Data was updated 0.000117 seconds ago

	Last value	Mean	Variance	Abs Max	Abs Min	Rel Max	Rel Min	Type
usecTime	5.565e+006	5.311e+006	6.426e+010	5.565e+006	9.918e+005	5.565e+006	9.918e+005	int32
CycleUsecTime	2.505e-004	2.529e-004	2.734e-009	7.997e-003	1.631e-005	7.997e-003	1.631e-005	float
waterHeightReference	2.068e+000	2.219e+000	2.369e-002	3.500e+000	2.068e+000	3.500e+000	2.068e+000	float
waterHeight	2.121e+000	2.278e+000	2.501e-002	3.540e+000	2.121e+000	3.540e+000	2.121e+000	float
pumpVoltageRequest	3.453e-001	3.575e-001	5.719e-003	1.220e+001	-5.590e+001	1.220e+001	-5.590e+001	float
pumpVoltage	3.453e-001	3.585e-001	4.261e-003	5.000e+000	0.000e+000	5.000e+000	0.000e+000	float

Integer 32 bits signals

	Decimal	Hex	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	09	08	07	06	05	04	03	02	01	00
usecTime	5565500	0x54ec3c	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1	1	1	0	1	1	0	0	0	0	1	1	1	1	0	0

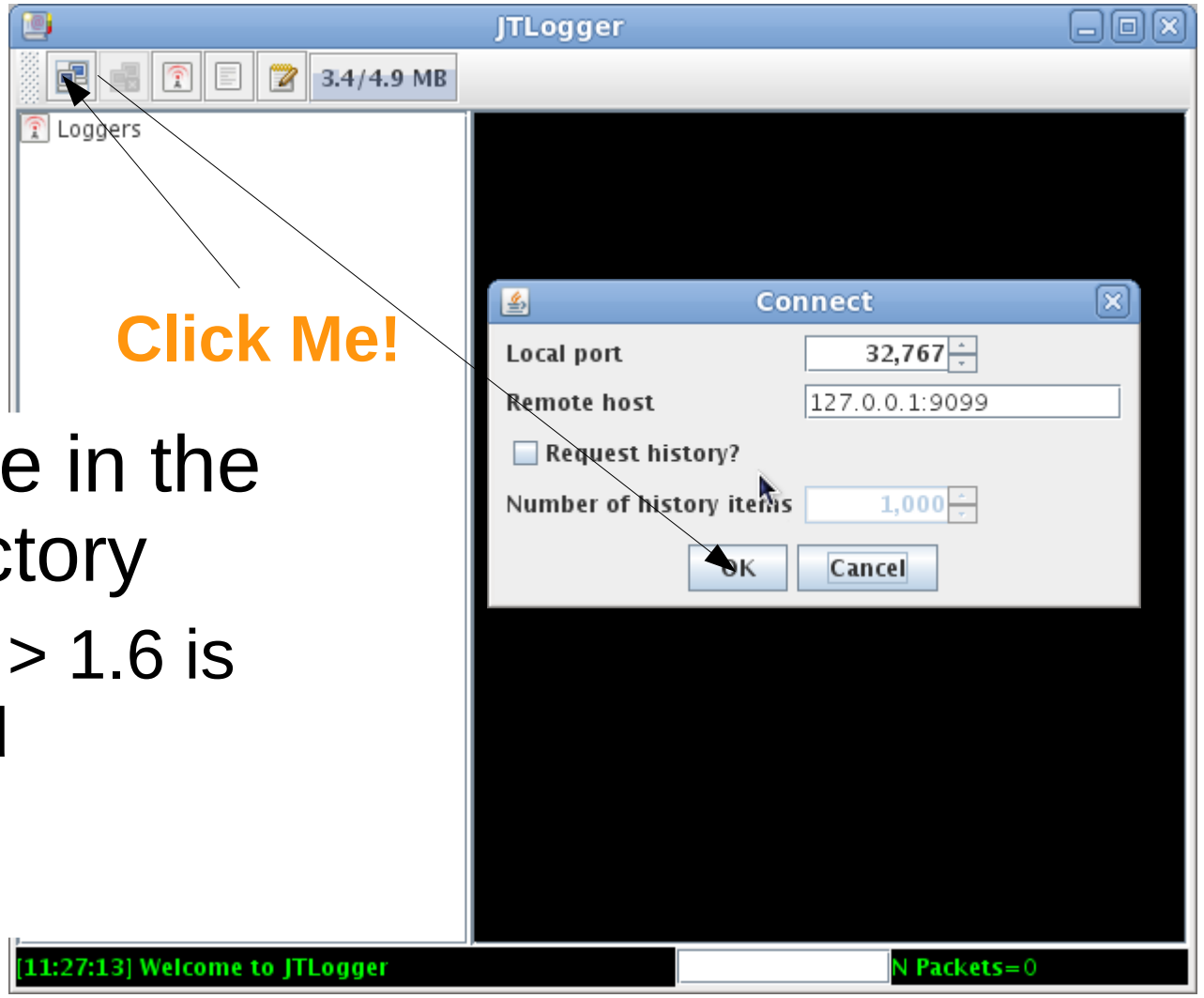
Integer 64 bits signals

Decimal	Hex	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23

Running the demo

- Install the executable on your computer
  - Linux users, remember to set the LD_LIBRARY_PATH to point to the location where you have installed MARTe
    - `e.g:export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:.`
  - `Mac users set your DYLD_LIBRARY_PATH`
    - `e.g:export DYLD_LIBRARY_PATH=$DYLD_LIBRARY_PATH:.`
  - Ubuntu users might require libtinfo (ncurses)
    - `sudo ln -s /usr/lib/libncurses.so.5 /usr/lib/libtinfo.so.5`
    - `sudo ln -s /usr/lib/libtinfo.so.5 /usr/lib/libtinfo.so`
  - Antivirus software might interfere with MARTe
    - (Disable it at your own risk)

Starting the logger



- Run the jar file in the *logger* directory
  - Sun Java > 1.6 is required

Starting MARTe

- MARTe can be run either as a service or as a console program
  - The latter will be used in this demo
- Start MARTe by executing MARTe.ex
  - If no parameters are given MARTe will look for a MARTe.cfg file in the same directory
    - Use this option for the demo
  - Otherwise it will assume the first parameter is a path to a configuration file

The logger is your friend...

```
[11:34:58]:localhost.localdomain:FatalError:tid=0xb78046d0 ():cid=0x0:obj=GLOBAL:InitGlobalContainer:: Failed opening file configurations/MARTe-WaterTank-OOOPSS.cfg
[11:34:58]:localhost.localdomain:Information:tid=0xb7820b70 ():cid=0x0:obj=GLOBAL:Switching log server to localhost:32767
[11:35:0]:localhost.localdomain:FatalError:tid=0xb78046d0 ():cid=0x0:obj=GLOBAL:MARTe:: MARTe Initialization has failed.
```

- Sometimes it can get too verbose
  - Use the menu on the left to filter accordingly to error (value < 1)
- Even if not demonstrated here the logger can be connected to a logger service
  - Stores logging history
  - Enables history retrieving
  - Logging broadcast across networks
  - Multi-client support

The MARTe console

- Menu automatically created accordingly to the configuration file
  - Obsolete, but quick, interface

```
##############################################################################
##                              MARTe Menu                                  ##
##############################################################################
                                      #
A:->         State Machine Interface  #
                                      #
B:->                           MARTe  #
                                      #
                                      #
                                      #
                                      #
                                      #
                                      #
                                      #
                                      #
                                      #
                                      #
                                      #
                                      #
                                      #
##############################################################################
0: EXIT
##############################################################################
```

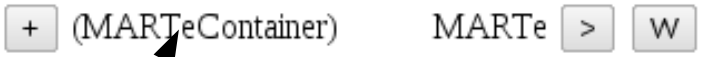
The HTTP interface

- Point your browser to http://localhost:8084
- Click on BROWSE
  - Any objects that implement the HTTP interface can be inspected
- Open the MARTe.cfg and compare with the object tree in your browser

```
+BROWSE = {
        Title = "Http Object Browser"
        Class = HttpGCRCBrowser
        AddReference = {MARTe StateMachine OBJBROWSE
THRBROWSE CFGUpload HTTPSignalServer MatlabSignalServer}
    }
```

Browsing objects

- Containers can be expanded to display their objects



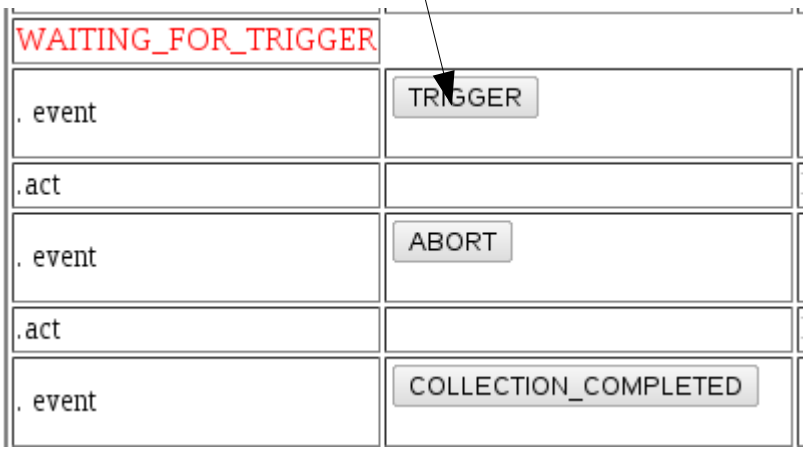
  - Click on the + symbol next to (MARTeContainer)
  - Click on the + symbol next to (RealtimeThread)
  - Two GAMs are displayed
  - Click on the > symbol next to Statistic
- Debug information can also be displayed using this interface
  - Click on THRBROWSE and OBJBROWSE

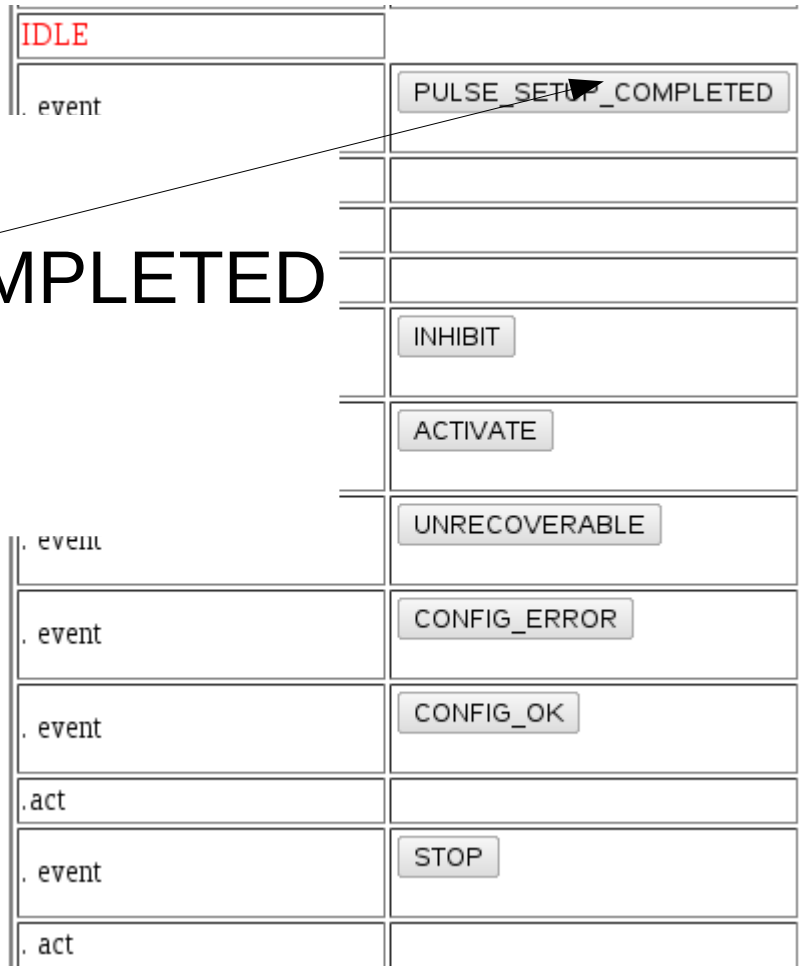
Loading a new configuration file

- *In a fully deployed production system this should be performed using other protocols...*
- Click on the *CFGUpload*
  - Select Wait reply
  - Select the configuration file *MARTe-WaterTank.cfg*
  - Click on the REFRESH button (upper left part of the screen)
- If you list the objects inside the RealtimeThread, you should see new GAMs...

Using the State machine

- Change to online
  - PULSE_SETUP_COMPLETED
  - TRIGGER



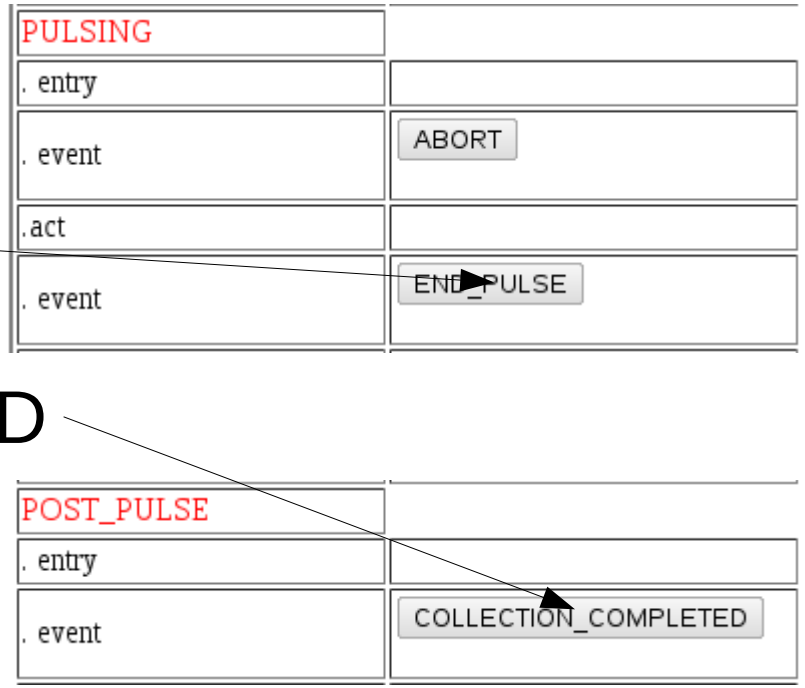


Figures of merit

- Visit the WebStatistics page
  - http://localhost:8084/BROWSE/MARTe/Thread_1/Statistic/
  - **CycleUsecTime**: the control cycle time
  - GAM_N_**RelativeUsecTime**: execution time of GAM_N
  - GAM_N_**AbsoluteUsecTime**: elapsed time from start of cycle until end of GAM_N execution
- More information in PlottingGAM and WaterTank:
  - http://localhost:8084/BROWSE/MARTe/Thread_1/PlottingGAM/
  - http://localhost:8084/BROWSE/MARTe/Thread_1/WaterTank/

Returning to offline...

- Back to StateMachine page
- Select END_PULSE
- Select COLLECTION_COMPLETED
- New configurations are only accepted when offline
- Data collection only possible in offline



Downloading acquired data

- HTTPSignalServer
  - Signals stored in ASCII format
- MatlabSignalServer
  - Signals store in Matlab format (can also be opened in Octave)
- Select the MatlabSignalServer
  - Select *Dump all signals to file* and *Send*

Analysing data (with octave)

- Open Octave and move to the folder to where the signals were download
- `octave:1> load allsignals.mat`
- `octave:2> whos`
- `octave:3> plot(TIME/1e6, WATERHEIGHTREFERENCE, TIME/1e6, WATERHEIGHT)`
- `octave:4> xlim([0 5])`
- `octave:5> plot(TIME/1e6, CYCLETIME)`
- `octave:6> xlim([1 2]);ylim([1e-3 5e-3])`

Bad configurations (1/2)

- Return to the CFGUpload
- Select the configuration file
  configurations/MARTe-WaterTank-bug.cfg
- And select Wait reply
- You should see
  - **MARTe replied: ERROR**
- Investigate the error in the logger

```
GLOBAL:Signal waterHeightReferences, used by PIDGAM with interface InputInterface reports error: missingSourceError.
(DDB *)0xb7600ae8:DDB::CheckAndAllocate(): One or more errors prevent DDB allocation.
0:obj=(RealTimeThread *)0x9fb0f08:RealTimeThread::CreatePerformanceMonitors4Gams: Thread_1: DDB CheckAndAllocate Failed
```

Bad configurations (2/2)

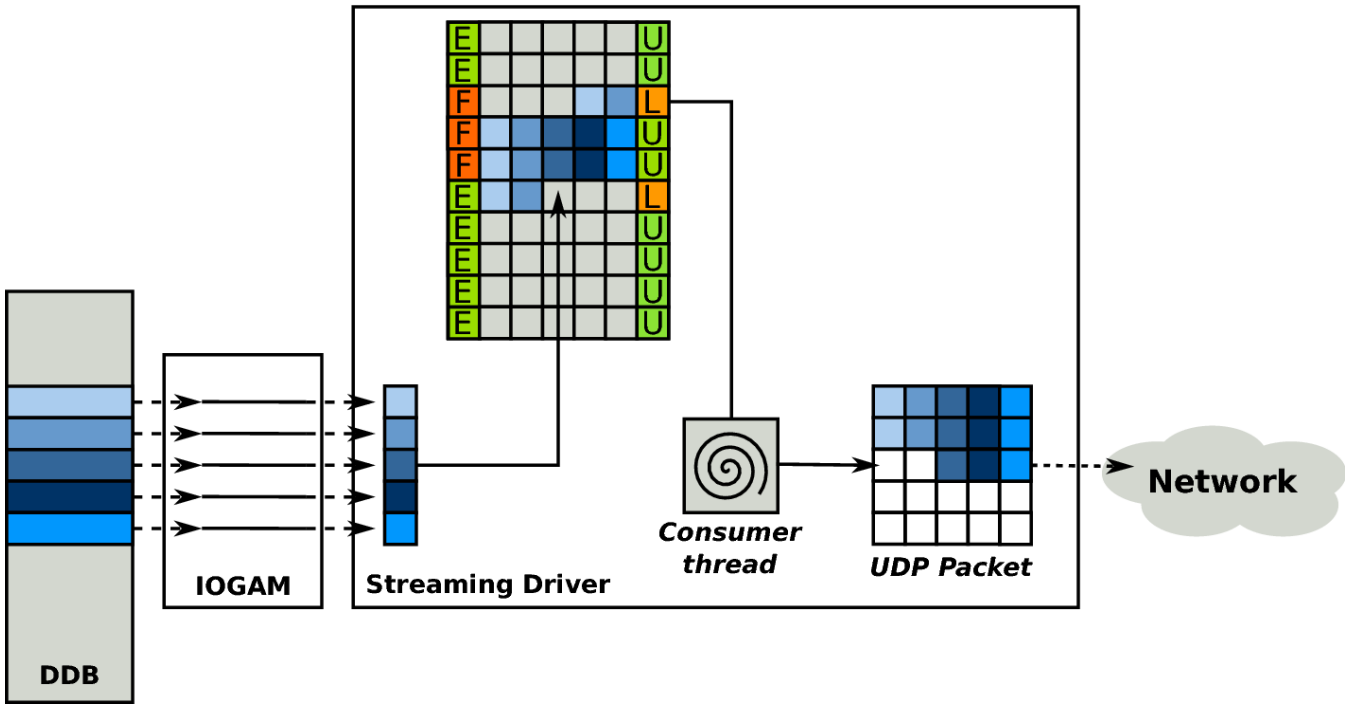
- State machine will go to ERROR
- Recover by loading the MARTe-WaterTank.cfg
- State machine will recover
- All states and error responses are configurable

ERROR	
. event	ACTIVATE
. event	COLLECTION_COMPLETED

IDLE	
. event	PULSE_SETUP_COMPLETED
.act	
.act	
.act	
. event	INHIBIT
. event	ACTIVATE
. event	UNRECOVERABLE

Streaming

- Streaming UDP driver
  - Connect several RT MARTe
  - Send data to an HMI



Main configuration parameters

```
+StreamingDrv = {
            Class = StreamingDriver
            NumberOfOutputs = 4
             NumberOfBuffers = 40
            NumberOfTransferBuffers = 1
            ReceiverUDPPort = 14500
            ReceiverUDPAddress = localhost
            CPUMask = 1
        }

+StreamingReceiver = {
            Class = StreamingDriverReceiver
            NumberOfInputs = 4
            NumberOfOutputs = 0
            NumberOfTransferBuffers = 1
            ReceiverUDPPort = 14500
            SynchronizationMethod = Synchronizing
            CPUMask = 1
        }
```

Running the example (1/2)

- Start one MARTe with the cfg. file
  configurations/MARTe-WaterTank-Streaming-Sender.cfg
- Start a second MARTe with the cfg.
  configurations/MARTe-WaterTank-Streaming-Receiver.cfg
- Go to the sender MARTe state machine
  - http://localhost:8084/BROWSE/
  - Change the status to online
- Go to the receiver MARTe
  - http://localhost:8085/BROWSE/
  - Check the statistics page

Running the example (2/2)

- Change the receiver state to online
- Visit the GAMs pages
  - Statistics
  - PlottingGAM
  - WaterTank

Backup slides