"FM 2008"

An industrial case: pitfalls and benefits of applying formal methods to the development of a network-centric RTOS

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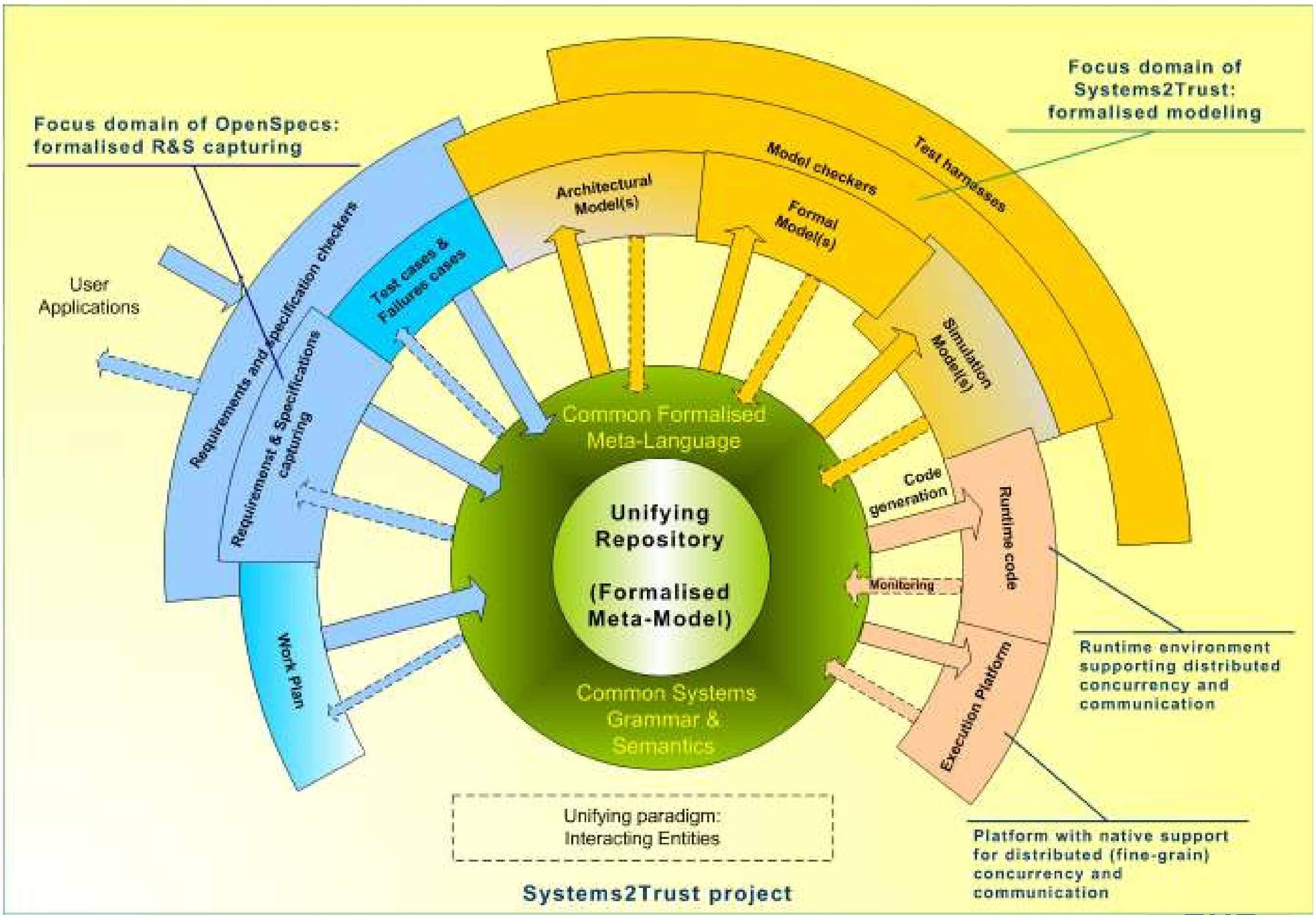
Who is Open License Society?

- Beyond "Open Source"
- Privately funded R&D institute
  - Leuven (BE), Berdyansk (UA)
  - Industrial sponsors
  - IWT project funding for OpenComRTOS
  - Results now commercialised via Altreonic Co.
- Why: 70 % of all SE projects do not deliver
- Objectives
  - Systematic & Unified Systems Engineering Methodology
  - 'Interacting Entities' paradigm at all levels:
    - OpenComRTOS as runtime environment (formally developed)
  - Implies 'Trustworthy Components'
    - => Open License (source code + all design, test, …. docs)
- Focus:
  - Embedded Systems:
    - Constraints driven development
    - Real-time, distributed, hardware & software, …



Can we trust our mind ?
That’s why we need formal(isation)

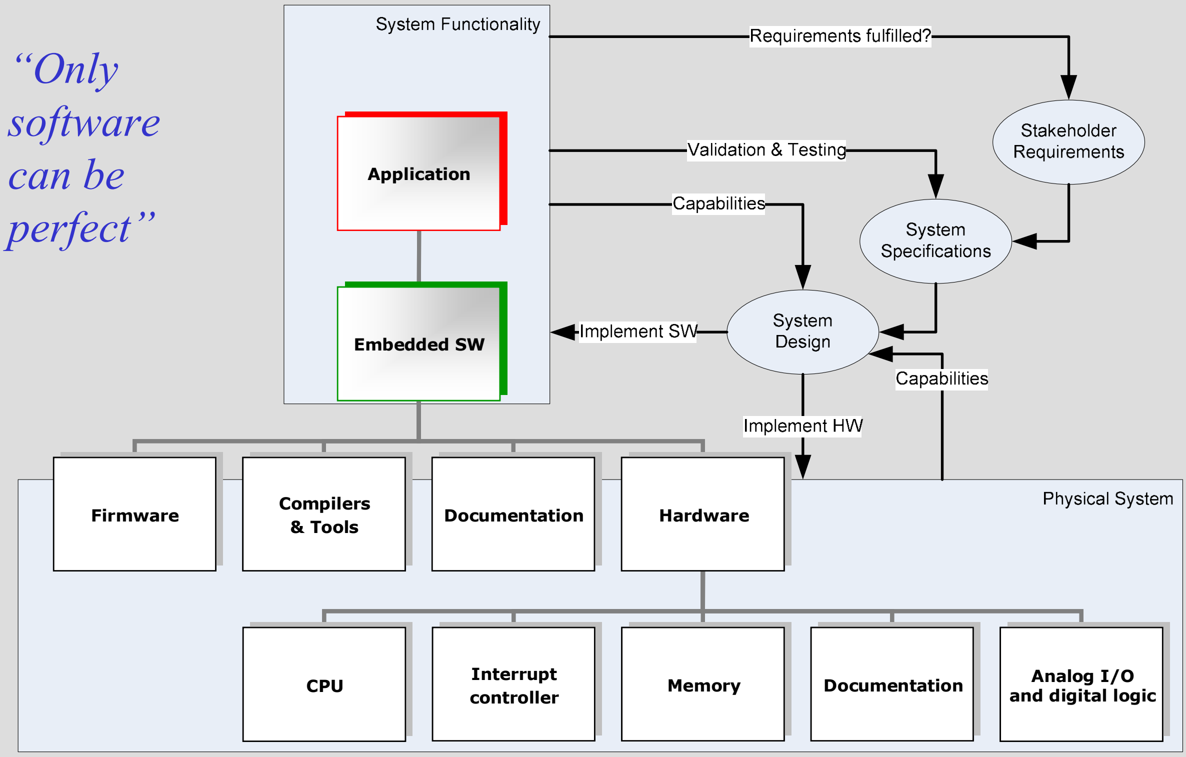
- Can you find the 3 letters « F » ?

FINISHED FILES ARE THE RE SULT OF YEARS OF SCIENTIF- IC STUDY COMBINED WITH THE EXPERIENCE OF YEARS

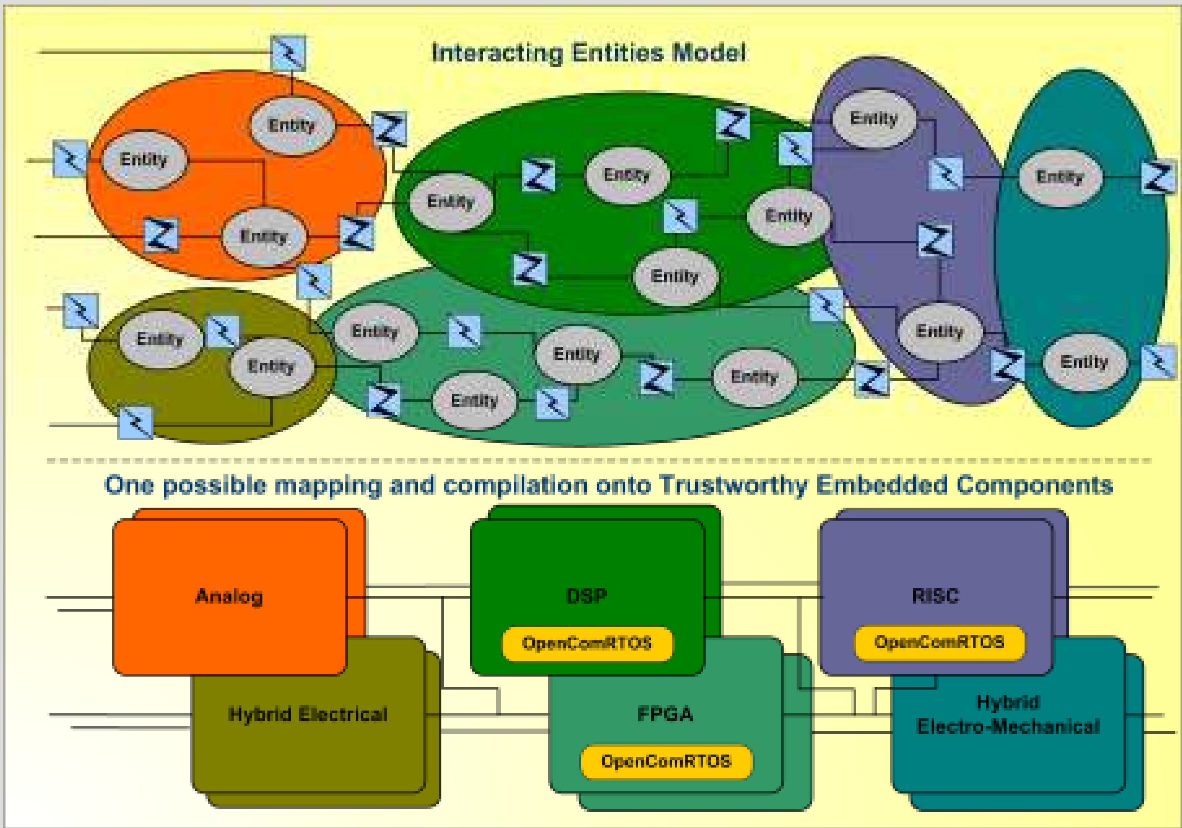
Did you see the similarity with source code (debugging) ?

Systems/Software Engineering Process dependency graph

"Only software can be perfect"



Unifying architectural paradigm: Interacting Entities



OpenComRTOS project objectives

- Funded R&D project (IWT, Flanders)
  - Lancelot Research: management, commercialisation
  - Open License Society: technology development
  - University Gent (INTEC, Prof. Boute): formal modeling
  - University Berdyansk: tools and formal validation
  - Melexis: co-sponsor and first user (16bit uC)
- GUI tools:
  - graphical modeling/development environment
- Goal:
  - Develop Trustworthy distributed RTOS
    - Follow OLS SE methodology
    - Formal verification & analysis: formal modelling
  - Scalable distributed RTOS
  - Verify benefits and issues of using Formal Modeling

Some requirements

- Targets:
  - Single chip, tightly coupled: multi-core
  - Multi-chip, tightly coupled: parallel processors on board
  - Multi-boards, multi-rack: using backplane interconnects
  - Distributed: using LAN and WAN
  - Host node
- Programming models:
  - "Interacting Entities"
  - "Virtual Single Processor":
    - transparent for topology
    - Supporting heterogenous targets
    - Write once, run everywhere
  - Distributed real-time
  - Safe, secure
  - Small code size, low latency (=high performance)

RTOS Metamodel

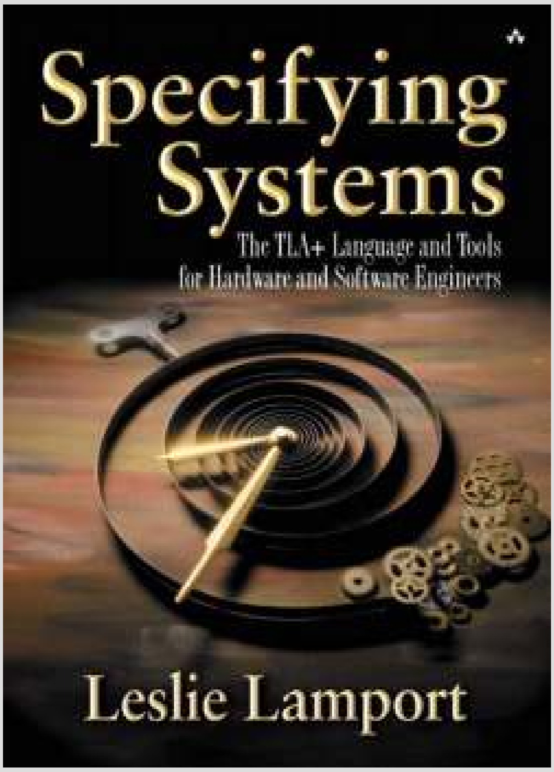
- Based on Interacting Entities Paradigm
- Application can be constructed from various entities (*kernel entities*) and interactions between them (*kernel services*).
- The Metamodel allows extensions to different sets of kernel entities and services of other RTOSes.
- Expression of the Metamodel in XML format

OpenComRTOS systems grammer

OpenComRTOS **IS_DEFINED_BY**
    Configuration (1)   // The root node of XML file
Configuration **IS_DEFINED_BY**   // Nodes of configuration section
    Parameters (1) **AND**   // *Attributes* of the configuration section of XML file
    SystemTasks (4) **AND**   // Kernel, Idle, Rx or Tx
    ApplicationTasks (1-N) **AND**
    Ports (1-N) **AND**
    Nodes (1-N) **AND**
    Links (1-N)
Configuration **HAS_ATTRIBUTES**   // Parameters
    DataSize (1) **AND**   // Packet data size (in bytes)
    NodeIdSize (1)   // Length of Node identifier (in bits)
SystemTask **CAN_BE**   // Type of system task
    KernelTask **OR**
    IdleTask **OR**
    RxTask **OR**
    TxTask
Etc.

TLA

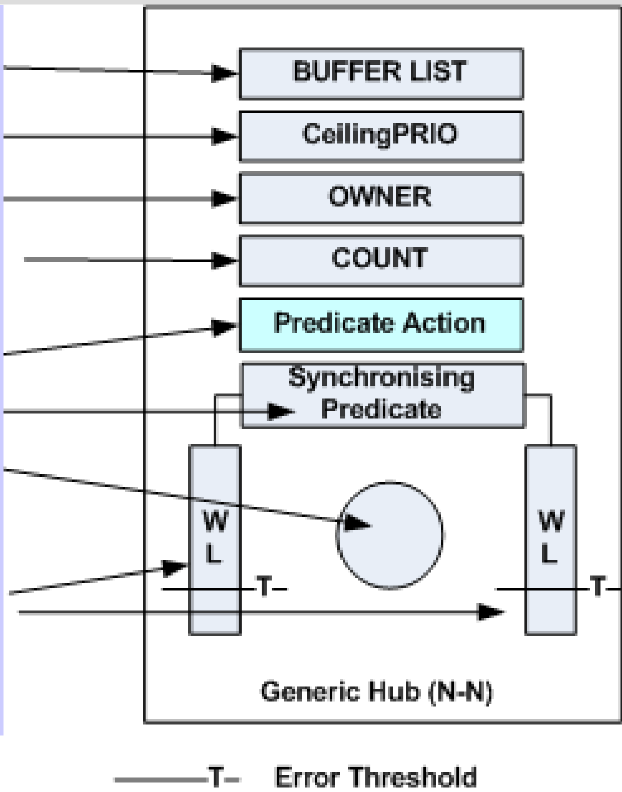
- **TLA** (the **Temporal Logic of Actions**) is a logic for specifying and reasoning about concurrent and reactive systems.



TLA modelling results

We modeled entities of OpenComRTOS:

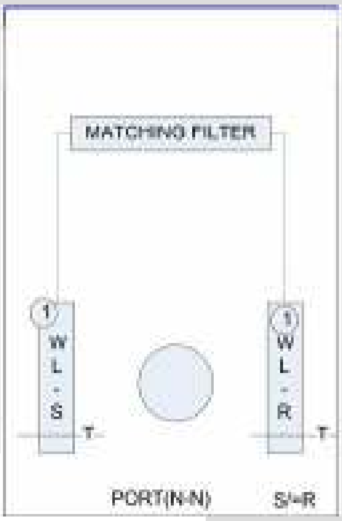
- Port
- Event
- Semaphore
- Resource
- Packet Pool
- Memory Pool
- FIFO
- Mailbox



Example: Port

Verified Properties:

- There are never more Tasks on the ready list than there are Tasks in the system
- There are never more Tasks in the Port's waiting list then there are Tasks in the system
- All Tasks waiting on an Port, either waiting to send a Packet, either waiting to receive a Packet are of the same type in each waiting list

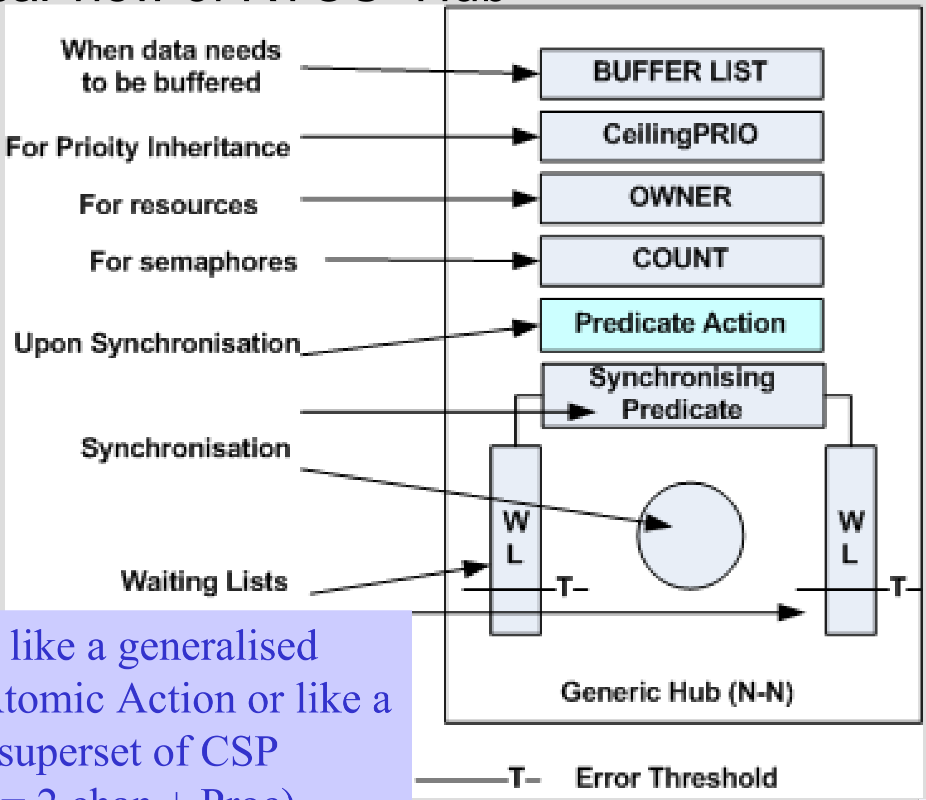


$$
\begin{aligned}
&TypeInvariant \triangleq \\
&\wedge\ Cardinality(ReadyList) \leq Cardinality(TaskId) \\
&\wedge\ \forall\, p \in PortId : \\
&Len(PortWL[p]) \leq Cardinality(TaskId) \\
&\wedge\ \forall\, p \in PortId : \\
&\forall\, i, j \in 1 \, .. \, Len(PortWL[p]) : \\
&PreallocatedPacket[PortWL[p][i]].type = PreallocatedPacket[PortWL[p][j]].type
\end{aligned}
$$

The OpencomRTOS "HUB"

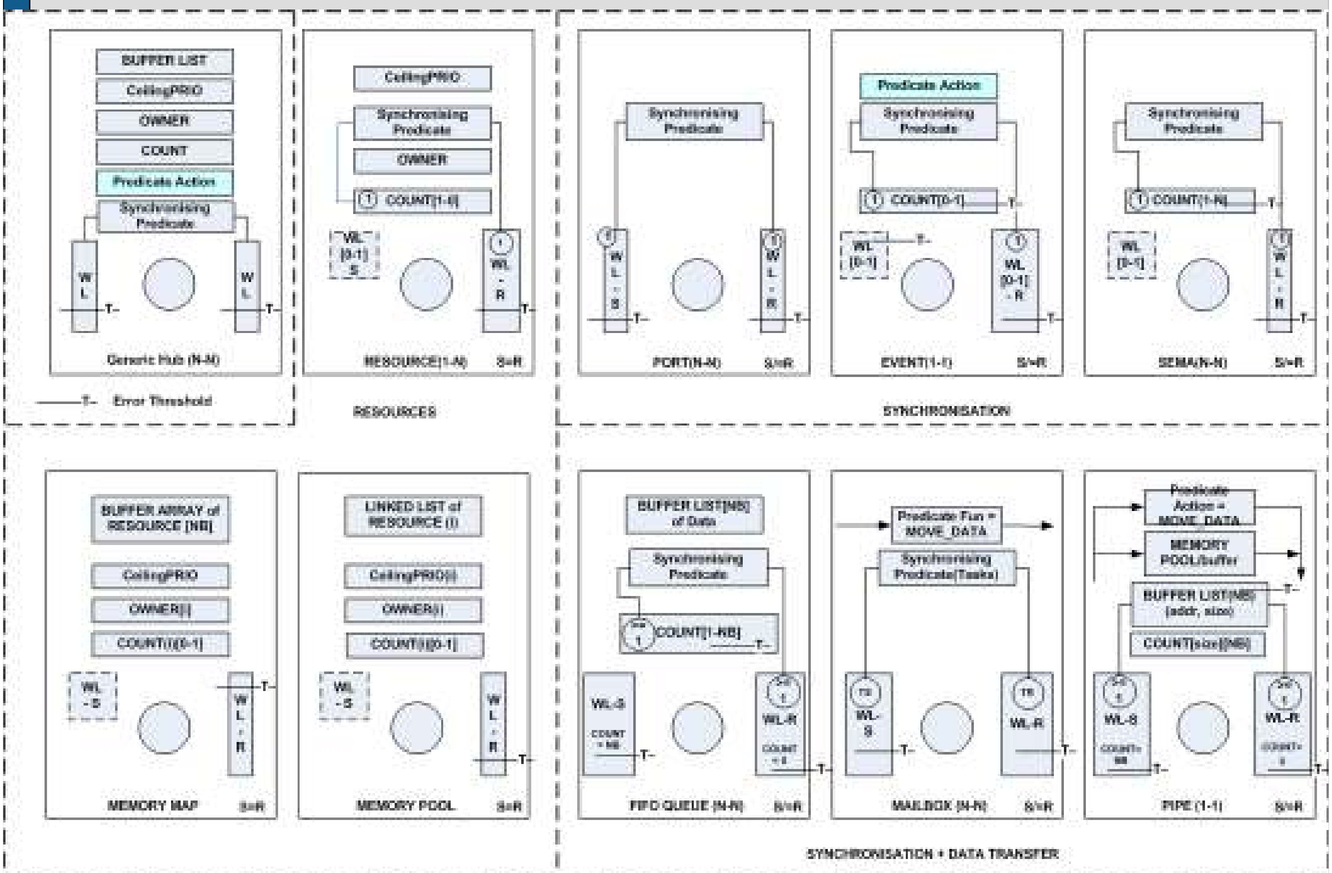
- Result of formal modeling
- Events, semaphores, FIFOs, Ports, resources, mailbox, memory pools, etc. are all variants of a generic HUB
- A HUB has 4 functional parts:
  - Synchronisation point between Tasks
  - Stores task's waiting state if needed
  - Predicate function: defines synchronisation conditions and lifts waiting state of tasks
  - Synchronisation function: functional behavior after synchronisation: can be anything, including passing data
- All HUBs operate system-wide, but transparently: Virtual Single Processor programming model
- Possibility to create application specific hubs & services! => a new concurrent programming model

Graphical view of RTOS “Hub”

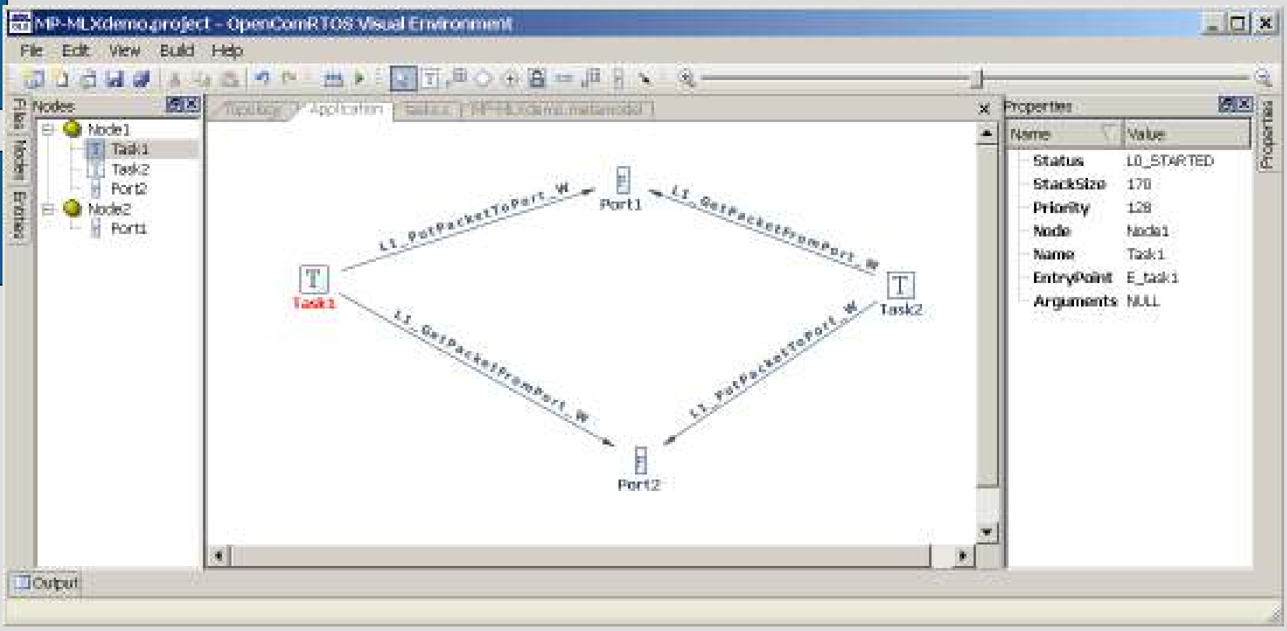


A “hub” is like a generalised Guarded Atomic Action or like a pragmatic superset of CSP channels (= 2 chan + Proc)

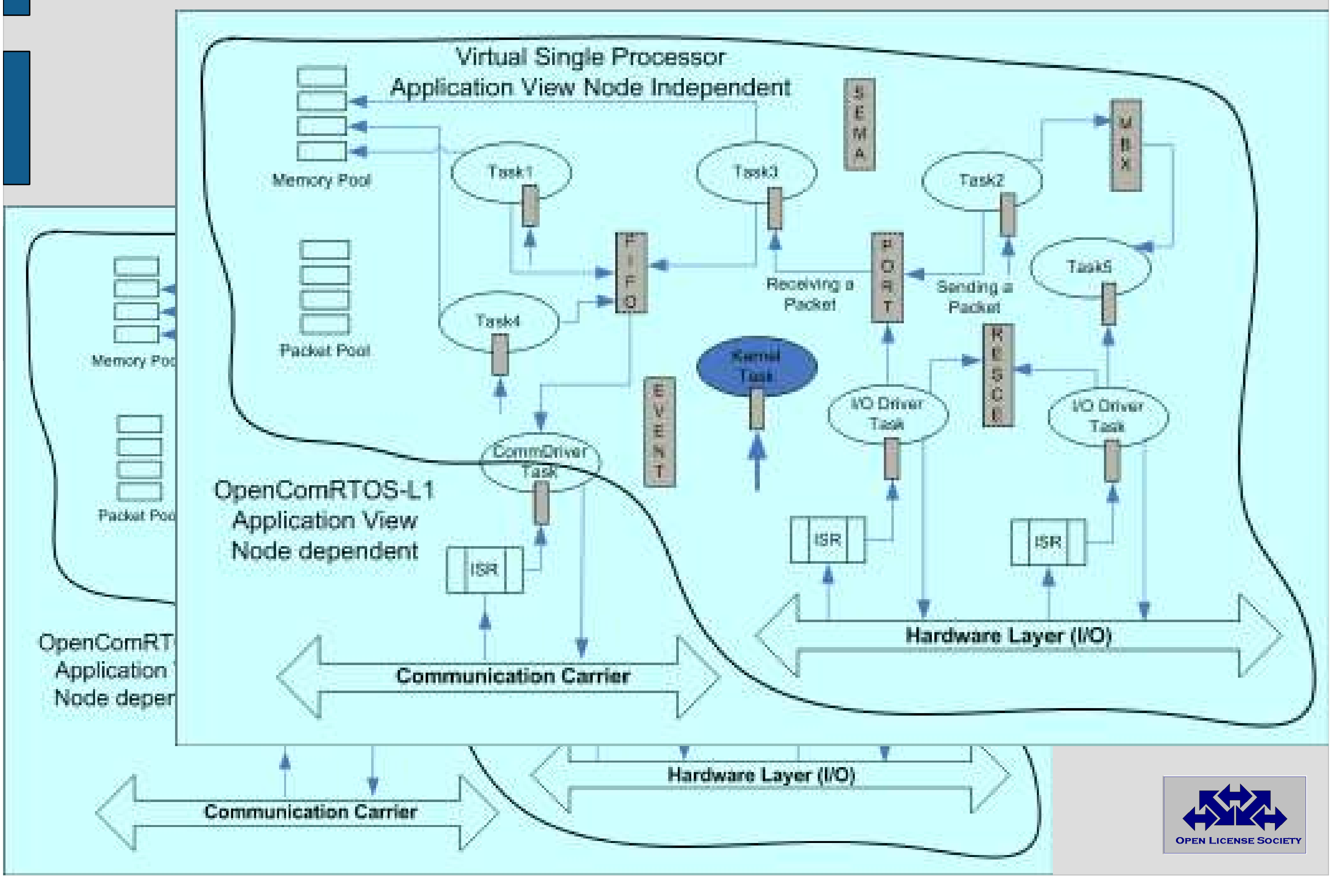
All RTOS entities are “HUBs”



Application's view



L1 application view:
any entity can be mapped onto any node



Clean architecture gives small code

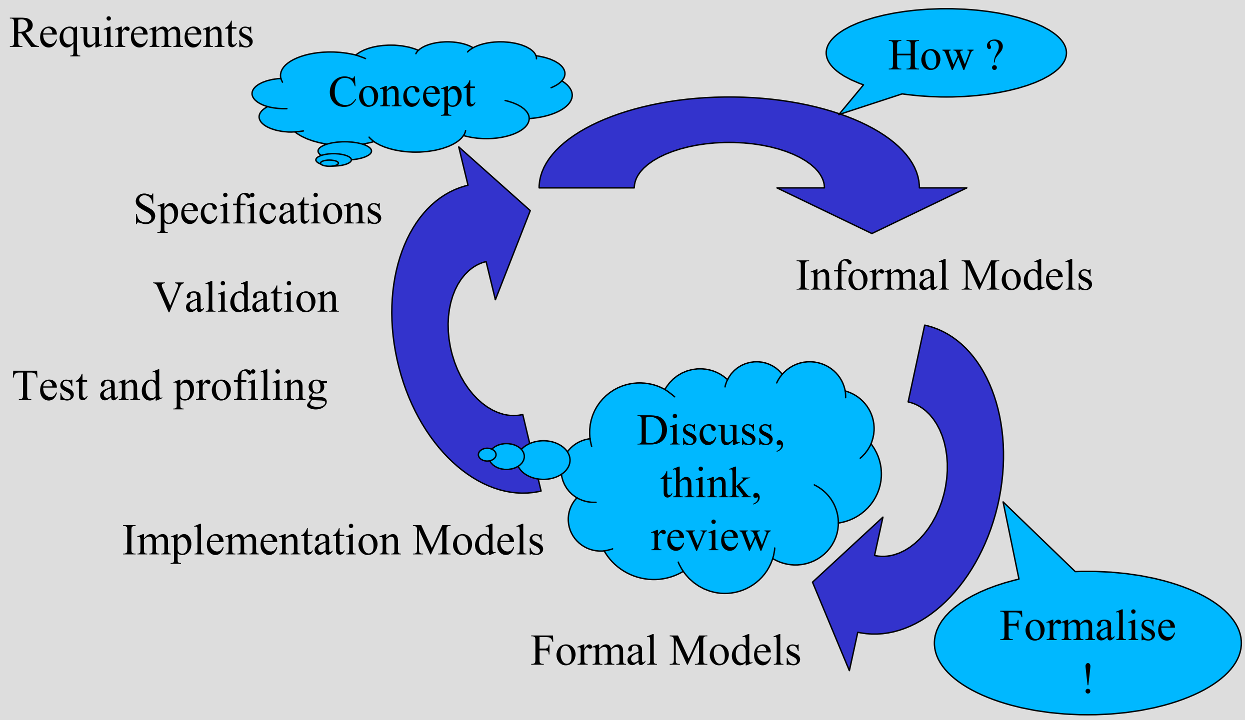
OpenComRTOS L1 code size figures (MLX16)				
	MP FULL		SP SMALL	
	L0	L1	L0	L1
L0 Port	162		132	
L1 Hub shared		574		400
L1 Port		4		4
L1 Event		68		70
L1 Semaphore		54		54
L1 Resource		104		104
L1 FIFO		232		232
L1 Resource List		184		184
Total L1 services		1220		1048
Grand Total	**3150**	**4532**	**996**	**2104**

Smallest application: 1048 bytes program code and 198 bytes RAM (data)
(SP, 2 tasks with 2 Ports sending/receiving Packets in a loop, ANSI-C)
Number of instructions : 605 instructions for one loop (= 2 x context switches, 2 x L0_SendPacket_W, 2 x L0_ReceivePacket_W)

Results

- Break-through results in well-known domain
  - 100's of RTOS with such support
  - 15 years of experience, 3 generations of RTOS design
  - Typically CPU dependent, use of assembler and async operation
- Small, scalable, distributed and maintainable code
  - SP(L0): < 1000 machine instructions
  - MP(L1): < 2000 - 5000 machine instructions
  - Yet all typical RTOS services (_NW|W|WT|Async)
  - Needs a few 100 bytes of data RAM
  - Fully in ANSI-C, MISRA-C compliant
  - Runs on MelexCM (16 bit), AVR, Win32, Linux, (Sparc, uBlaze, …)
  - Scheduling algorithm can be improved to reduce worst-case rescheduling latency and blocking time
  - All RTOS Entities are variations of a generic « hub » entity
    - => less but faster code: 5 KBytes vs. 50 KBytes before

How it really works: teamwork



From theoretical concept to products

Altreonic

From Deep Space to Deep Sea

"If it doesn't work, it must be art.
If it does, it was real engineering"