# Rule Control of Teleo-Reactive, Multi-tasking, Communicating Robotic Agents

Robotic agent programming in QuLog and TeleoR

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# Baxter two arm concurrent tower building

# QuLog - a modern logic programming language

- **Flexibly typed, multi-threaded, higher order**
- **Relation and function defining rules** - The declarative subset
  - Relation rules more declarative than Prolog
  - Relations must have their modes of use declared
    - *which arguments must be given, which may be returned*
  - Used to encode the agent's knowledge
- **Dynamic relations** - defined *only by facts*
  - Like tuples of a relational DB
  - Used for the agent's dynamic beliefs – its *Belief Store* (BS)
- **Top layer of action rules** – the imperative subset
  - Threads execute actions
  - Primitive actions – thread forking, I/O, inter-agent comms, BS updating

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# TeleoR

- Application specific extension of QuLog to facilitate programming of robust, goal directed, concurrently executing robotic device control threads
- Major development of Nilsson's T-R robotic language of
  *guard ~> action*
  rules sequenced into parameterised procedures
- T-R has its roots in the triangular table representation of the generalised plans of first AI robot – SRI's Shakey of late 1960s
- TeleoR's rule guards are QuLog queries to the agent's BS, optionally using its knowledge
- Compile time guarantee of fully determined and type correct robot actions
- High level multi-tasking using task atomic procedures
- Formal state transition semantics

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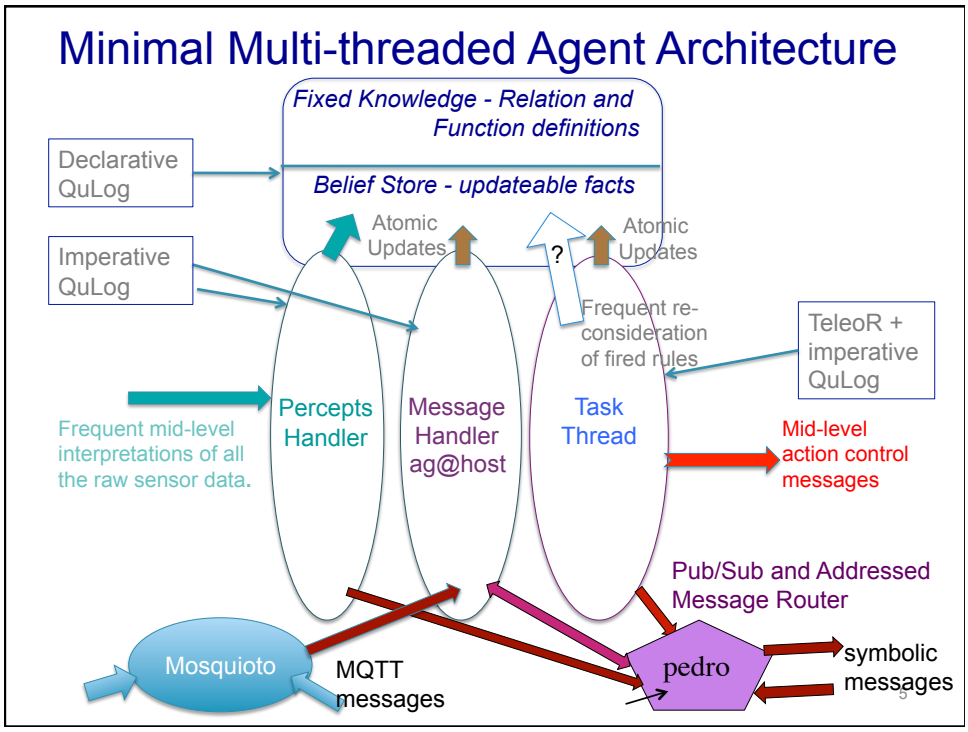
Minimal Multi-threaded Agent Architecture
Fixed Knowledge - Relation and Function definitions
Belief Store - updateable facts
Declarative QuLog
Imperative QuLog
Atomic Updates
Atomic Updates
?
Frequent re-consideration of fired rules
TeleoR + imperative QuLog
Frequent mid-level interpretations of all the raw sensor data.
Percepts Handler
Message Handler ag@host
Task Thread
Mid-level action control messages
Pub/Sub and Addressed Message Router
Mosquioto
MQTT messages
pedro
symbolic messages
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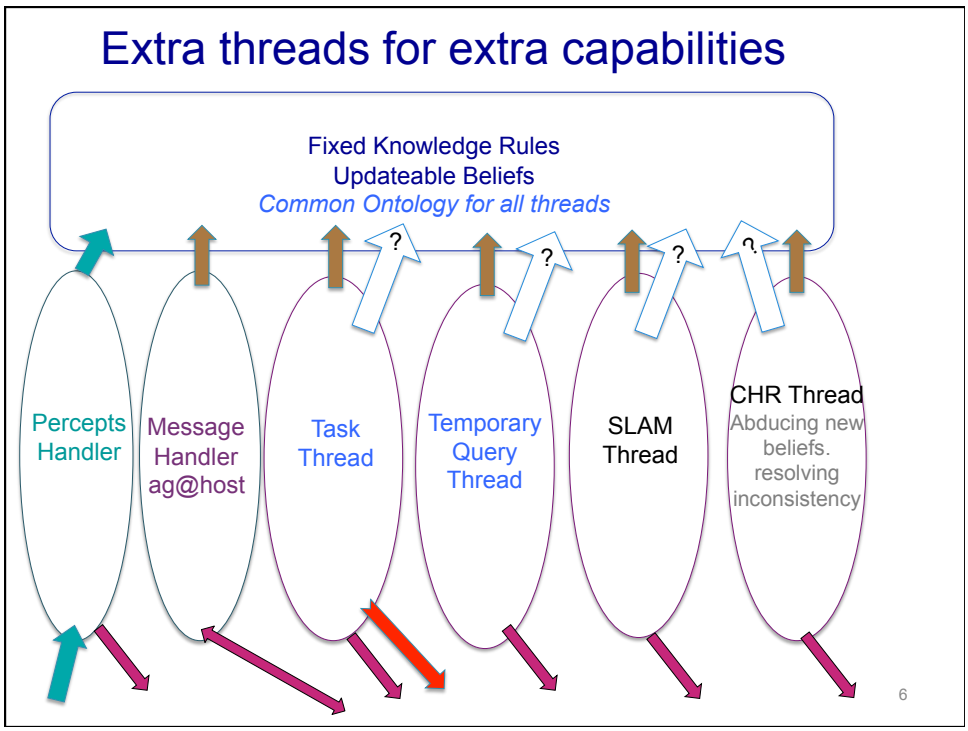
Extra threads for extra capabilities
Fixed Knowledge Rules
Updateable Beliefs
Common Ontology for all threads
?
?
?
?
Percepts Handler
Message Handler ag@host
Task Thread
Temporary Query Thread
SLAM Thread
CHR Thread
Abducing new beliefs. resolving inconsistency
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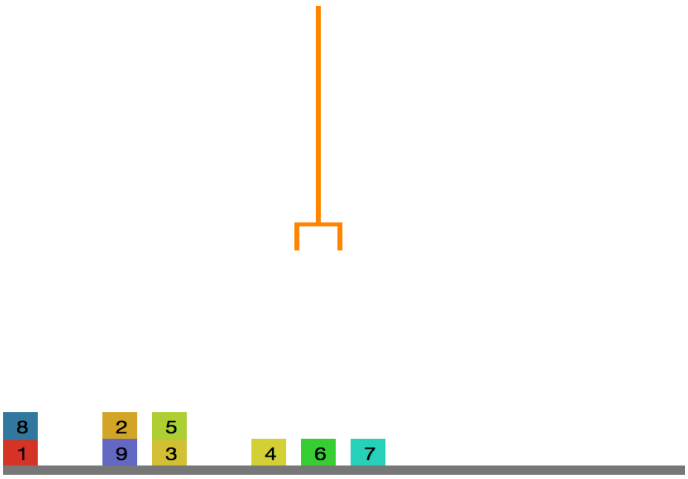
# One arm block tower building




t1 : [2, 5, 9, 6]

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# Task Knowledge

```
def block::= 1..9

durative  pickup(block),  put_on_block(block),  put_on_table()
percept   on(block,block),  on_table(block), holding(block)

rel sub_tower(list(block)), tower(list(block)), clear(block)
fun top(list(block)) -> block, tail(list(block)) -> list(block)

sub_tower([B]) <= on_table(B)
sub_tower([B1,B2,..Blocks]) <=
     on(B1,B2) & sub_tower([B2,..Blocks])

tower([B,..Bs]) <= clear(B) & sub_tower([B,..Blocks])

clear(B) <= not exists OtherB on(OtherB,B)

top([B ,.. _) -> B
tail([_ ,.. Bs] -> Bs
```

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# Control Knowledge

## Universal conditional top-level plan for block tower building

```
tel  makeTower(list(block))

makeTower(Blocks){

    tower(Blocks)  ~> ()  % Goal holds, do nothing

    sub_tower(Blocks) ~> make_clear(top(Blocks))

    tower(tail(Blocks)) ~>
          move_to_block(head(Blocks), head(tail(Blocks)))

    Blocks=[B] ~> move_to_table(B)

    true ~> makeTower(tail(Blocks))
    }
```

Action normally, eventually achieves

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# Mutually recursive control procedures

```
tel make_clear(block)
make_clear(Block){

   clear(Block) ~> ()  % Goal is achieved

   on(OnBlock,Block) ~> move_to_table(OnBlock)
   }
tel move_to_table(block)
move_to_table(OnBlock){

   on_table(OnBlock) ~> ()  % Goal is achieved

   holding(OnBlock) ~> put_on_table()

   clear(OnBlock) & not holding(_) ~> pickup(OnBlock)

   not holding(_)  ~> make_clear(OnBlock)

   holding(_) ~> put_on_table()
   }
```

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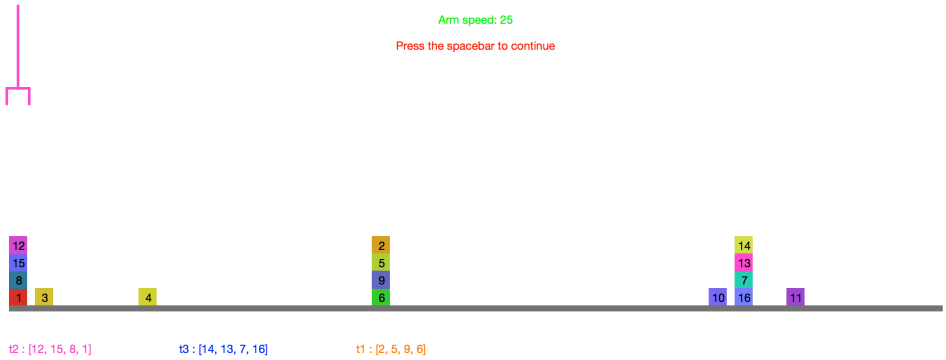
## Concurrent Task Tower Building

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## Update of single task tower builder

Just need to add:

task_start makeTower

task_atomic move_to_table, move_to_block

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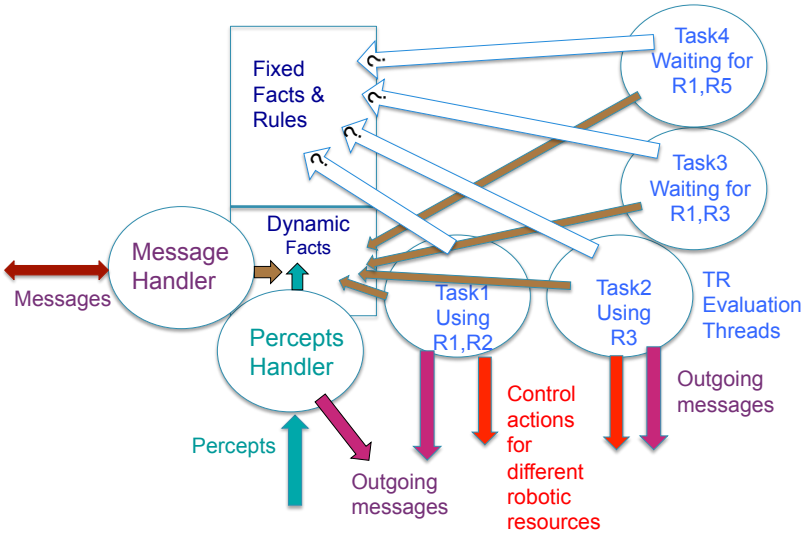
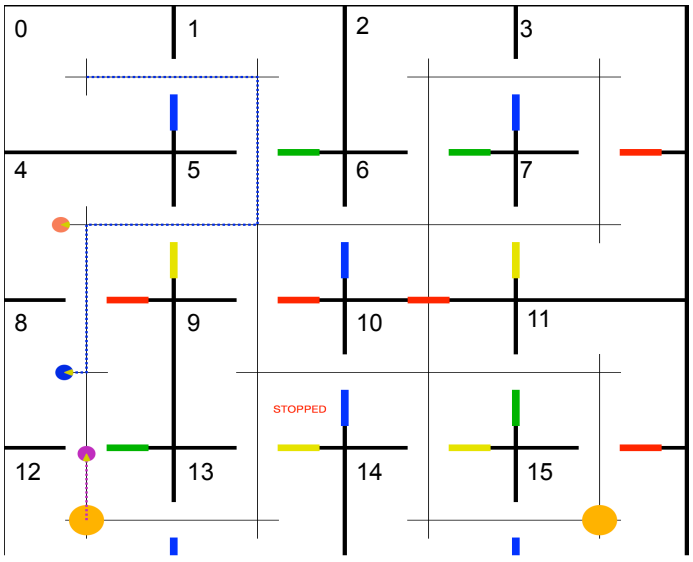
# Multi-tasking architecture




# Co-operative navigation

Blue robot path [(blue,1,0), (green,5,1), (yellow,4,5), (red,8,4)]

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# Common beliefs of agents

- The topological map of rooms and doors.
  e.g. connected(blue,1,2,90), connected(blue,2,1,270)
- Which chargers are 'reserved'
- Which doors are closed
  - this may be inaccurate
- Location of each robot
- Each robot's current path, if any

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# The task knowledge

```
def room ::= 0..15
def door_status ::= open | shut
def battery_status :: high | low
def door ::= blue | green | yellow | red
def path == list((door,room,room))  % type macro
def message ::= new_loc(robot,room) | path(robot,path) |
                staying(robot) | backed_up(robot,room,door) | ..
% message is a reserved type name

durative  turn(turn_dir), forward(),  reverse()
percept battery(battery_status), see_door(door, door_status),
        see_centre_ahead(), see_centre_close(), at_room_centre(),
        in_doorway(door), facing(door)

dyn loc(robot, room), open(door,room), reserved(robot, room),
    following(robot, room, path)

rel connected(?door,?room,?room), charger_room(?room),
   home_room(?robot,?room), ...
```

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# Recursive path follow procedure

```
tel follow(robot, room, path)

follow(Me, DestRm, Path) {

   loc(Me, DestRm) ~> ()

   loc(Me, Rm) & Path=[ (Door, Rm, DestRm),.. ] &
        connected(Door, Rm, DestRm, DoorDir) ~>
              move_to_next_room(Me, Rm, DestRm, DoorDir)

   Path=[ (_, Rm, DestRm),..PriorPath ] ~>
              follow(Me, Rm, PriorPath)
   % recursive call to get robot into Rm
   }
```

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# Top level navigation

```
tel get_to_room(robot, rel(?room)) % Higher order, 2nd arg a monadic rel.
get_to_room(Me,DestTest){

  loc(Me, MyRm) & DestTest(MyRm) ~> ()

  following(Me,DestRm,Path) &
      rem_path_open_and_shortest_to_dest(Me,Path,DestTest) ~>
            follow(Me, DestRm, Path)

  loc(Me, MyRm) &
    graph_path(MyRm, DestRm, Path, open_connected, DestTest)) ~>
              () ++ new_path(Me, DestRm, Path) to pedro

  true ~> stay_avoiding_other_robots(Me) ++ staying(Me) to pedro
  }

rel open_connected(door,room,room)
open_connected(Door,Rm1,Rm2) <=
    connected(Door,Rm1,Rm2,_) & open(Rm1,Door)
```

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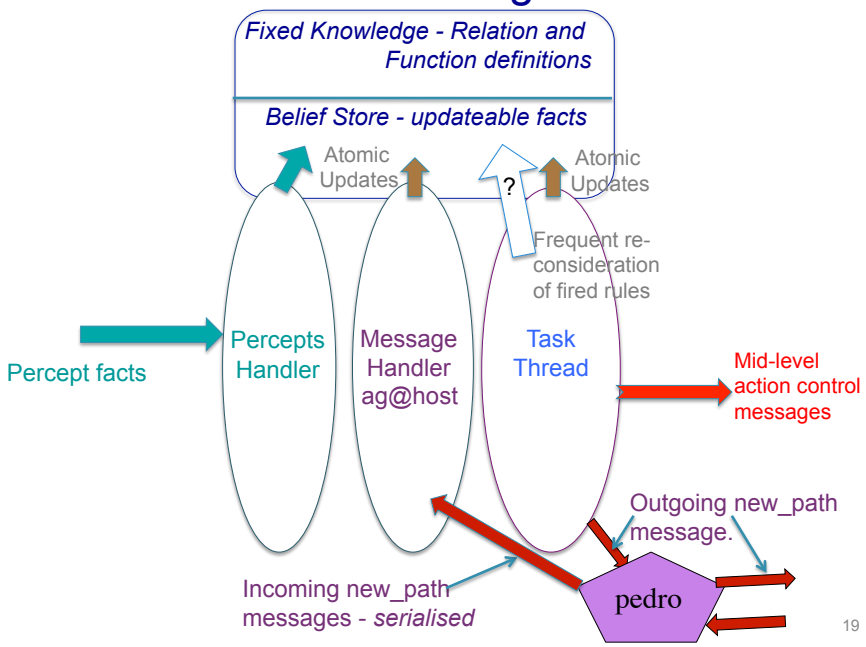
# Minimal Multi-threaded Agent Architecture

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# Delivery robots in Japan

https://youtu.be/_QndP_PCRSw


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# TeleoR semantics and implementation

- Formal State Transition Semantics
- Optimized Reference Implementation
  - Runtime system that implements state transition semantics
  - Compile time analysis ensures rule guards are not re-evaluated on *BS* update if no relevant change made
- Currently compiled to multi-threaded Qu-Prolog
- Will be compiled to specialized Abstract Machine Code similar to but simpler than Warren's Prolog Abstract Machine Code

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# Sources and software

Clark & Robinson, Robotic Agent Programming in TeleoR, *ICRA 2015*, IEEE

Clark & Robinson, Concurrent Task Programming of Robotic Agents in TeleoR, Invited Paper and Demo, Rule-ML 2017 Challenge, on http://ceur-ws.org/Vol-1875/

Clark et al, A Framework for Integrating Symbolic and Sub-symbolic Representations, *IJCAI 2016*, AAAI Press

*Programming Communicating Multi-tasking Robotic Agents: A Teleo-Reactive Rule Based Approach,* Springer, 2019
first 5 chapters at teleoreactiveprograms.net

TeleoR and QuLog Software for Unix, Linux and OS X at
http://staff.itee.uq.edu.au/pjr/HomePages/QulogHome.html

Collaboration and users welcomed

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