Cancellable Servers:
a Pattern for Curiosity

Peter Welch (**phw@kent.ac.uk**)

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Curiosity on Mars

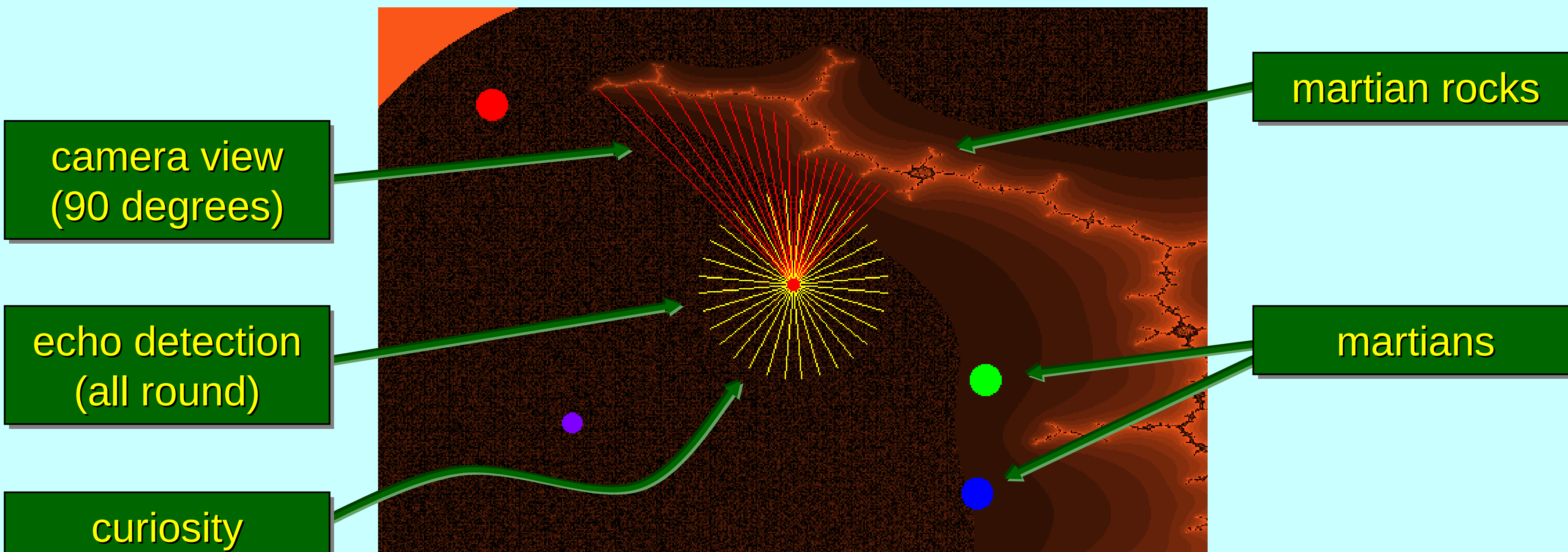
This is a student exercise to design and implement part of the control logic for an autonomous **`robot.control`** process for a rover vehicle on Mars.

Run Demo …

Curiosity on Mars

This is a student exercise to design and implement part of the control logic for an autonomous **`robot.control`** process for a rover vehicle on Mars.

The controller has to respond to commands from its operator back on Earth, to operate simple actuators (start/stop motors, deploy gadgets) and to monitor and respond appropriately to input from peripherals (motor feedback clicks, raw echo sensor data, processed camera images).



Curiosity on Mars

This is a student exercise to design and implement part of the control logic for an autonomous `robot.control` process for a rover vehicle on Mars.

The controller has to respond to commands from its operator back on Earth, to operate simple actuators (start/stop motors, deploy gadgets) and to monitor and respond appropriately to input from peripherals (motor feedback clicks, raw echo sensor data, processed camera images).

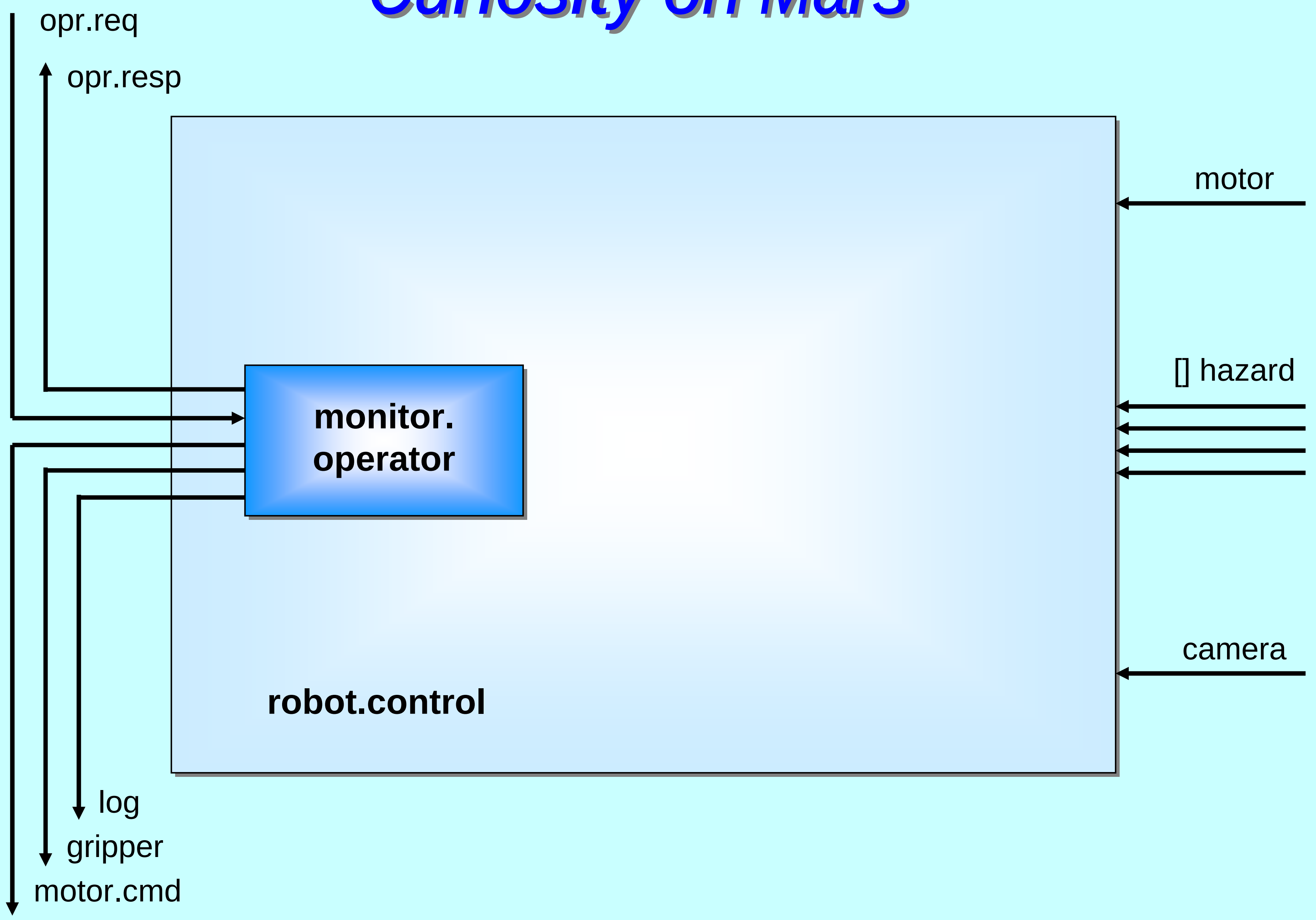
This *could* be implemented by a purely sequential process … *but that's hard*.

A concurrent implementation is simpler, with a process for each external agent (mission control, motor, echo sounder and camera). These processes are linked and communicate as a *client/server* network.

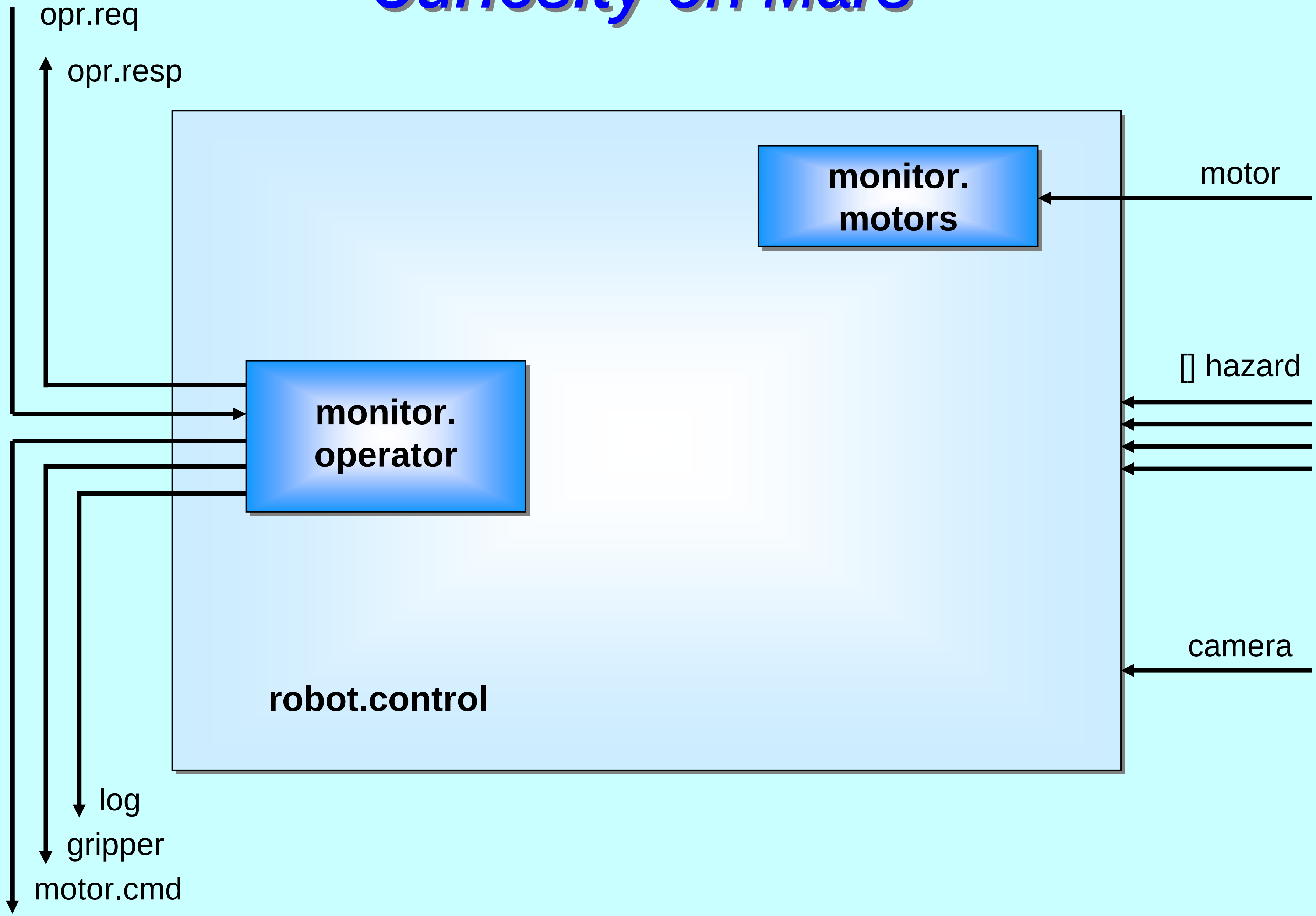
One twist is that three of the servers must be *cancellable* (since two transactions need to run in parallel, with the first to complete causing the cancelation of the other).

Curiosity on Mars

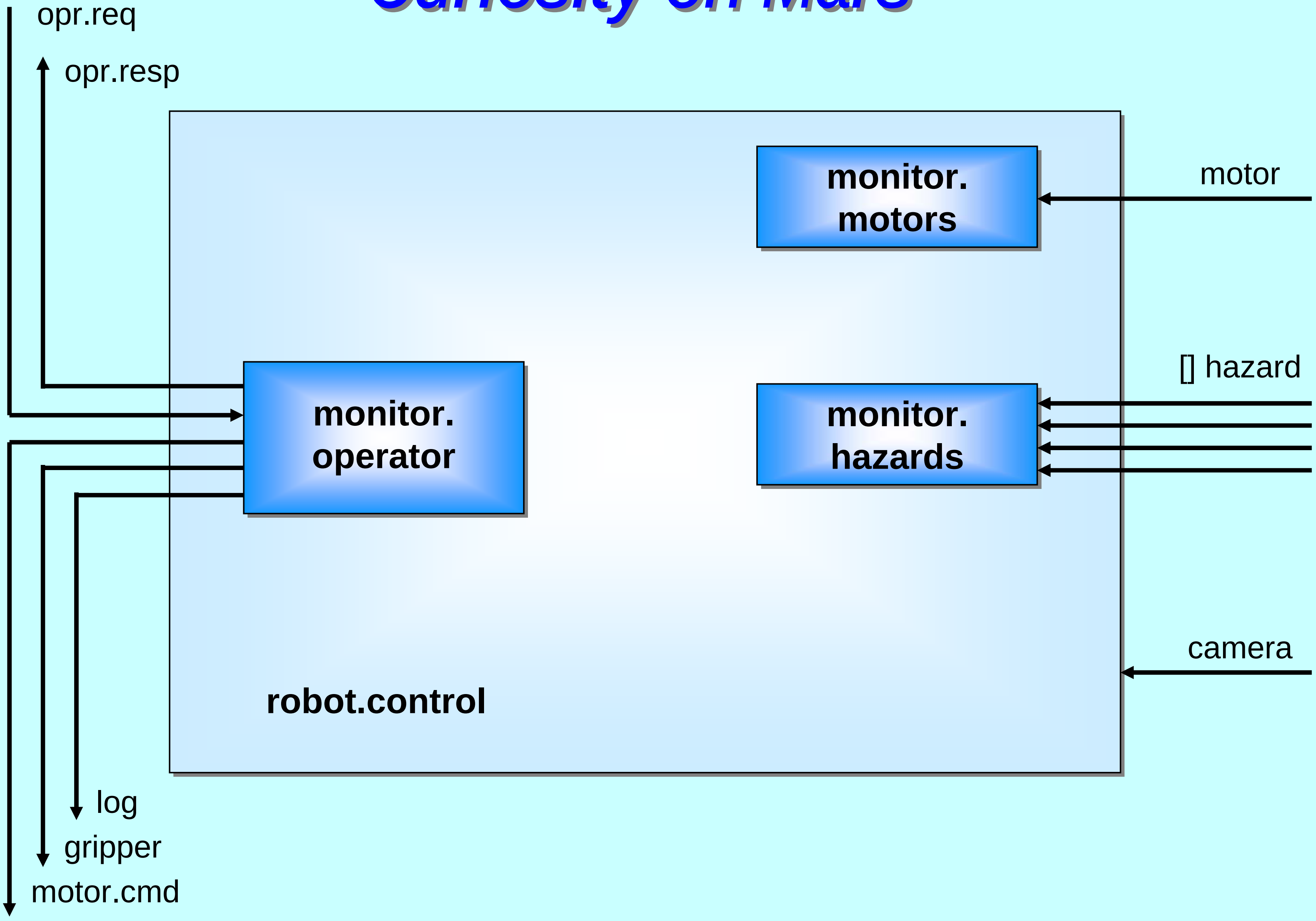
Curiosity on Mars



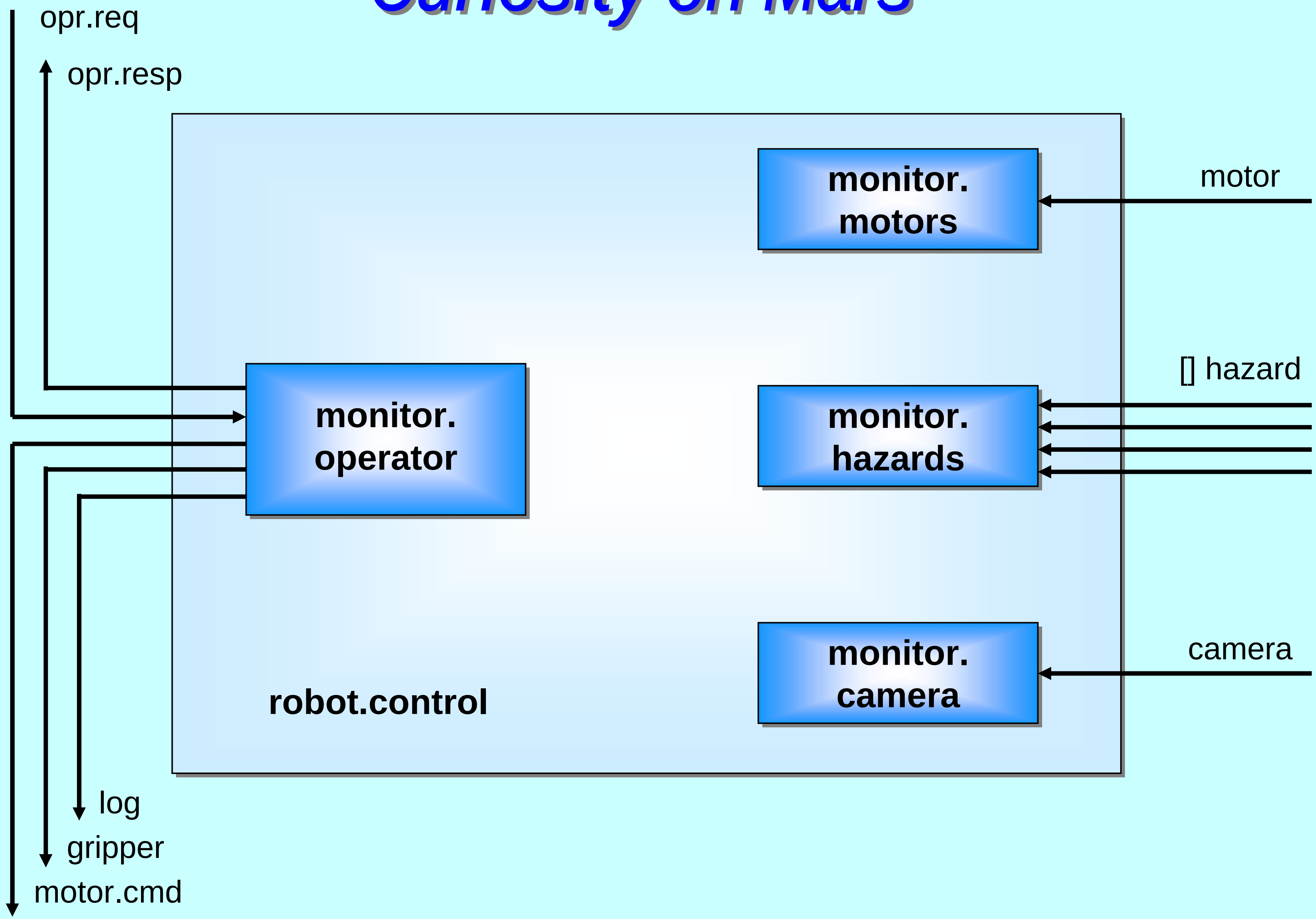
Curiosity on Mars



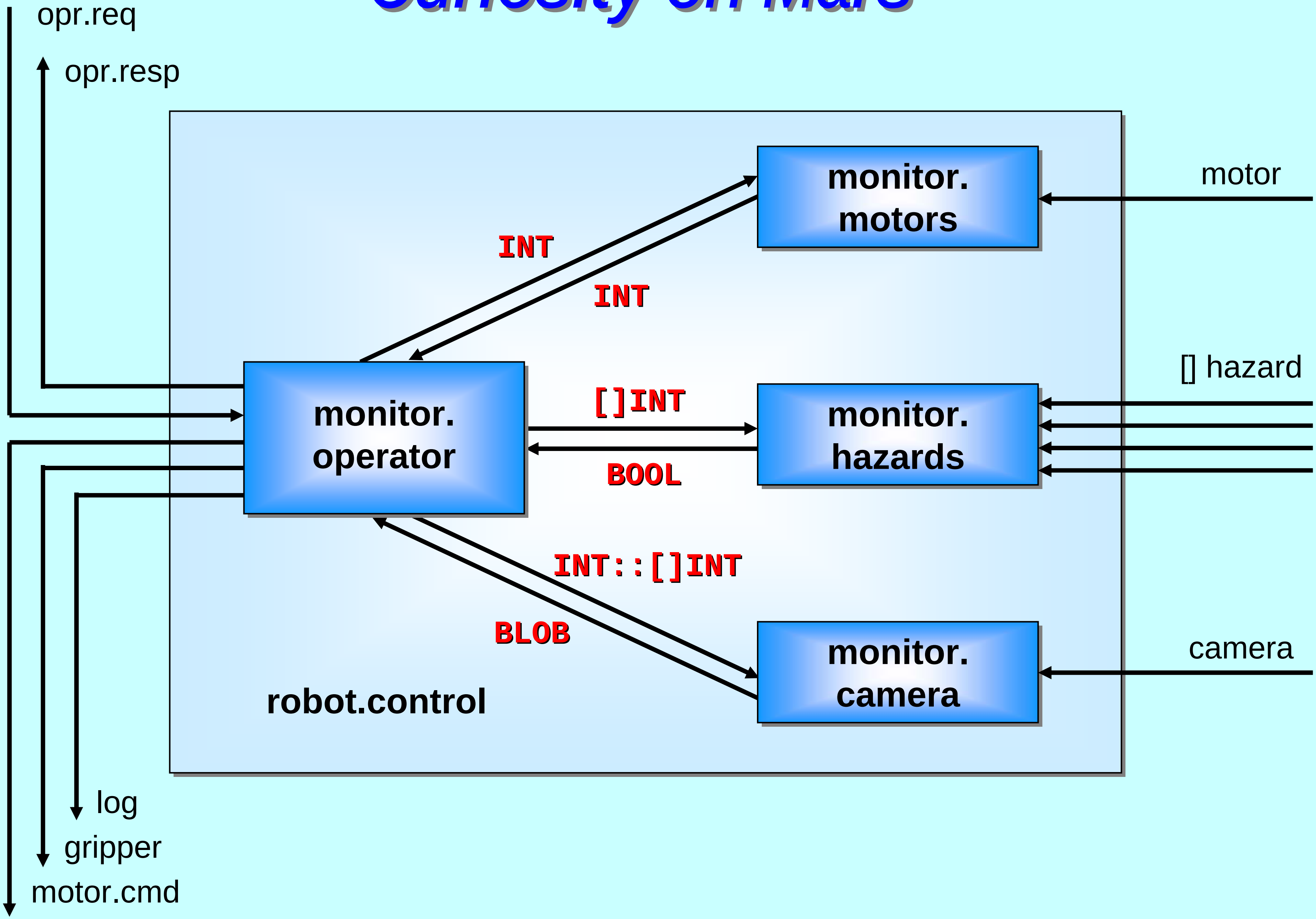
Curiosity on Mars



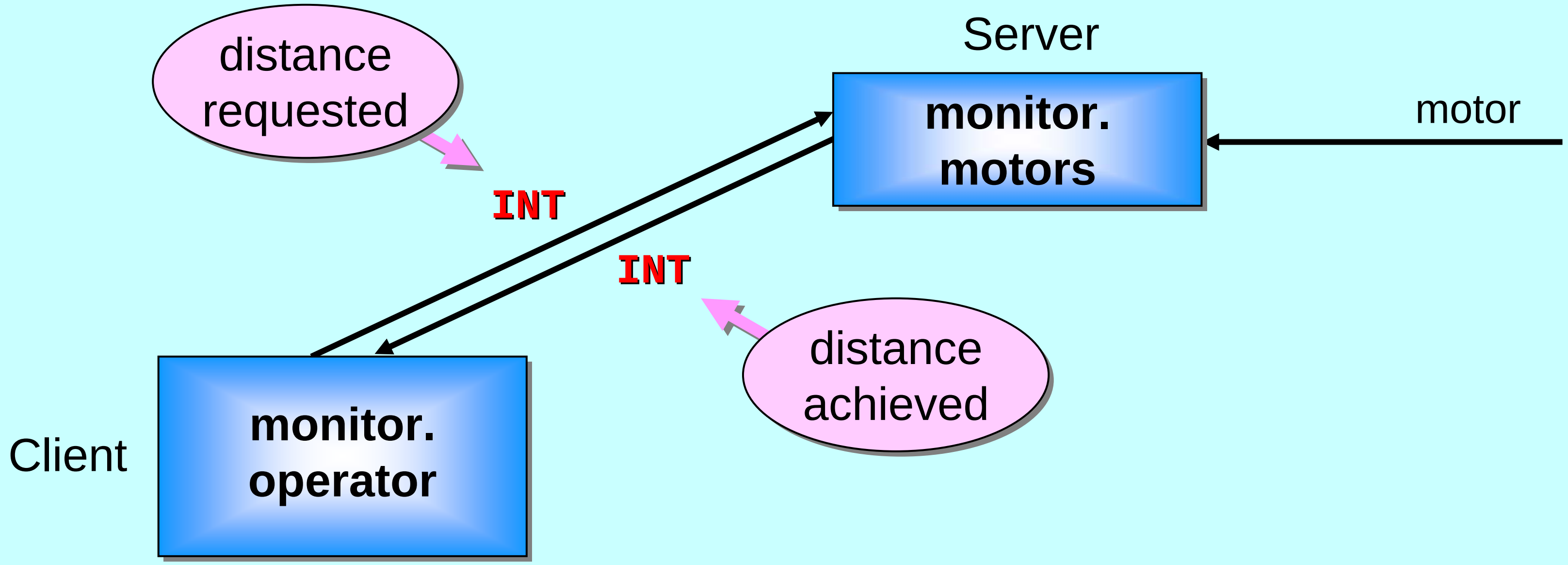
Curiosity on Mars



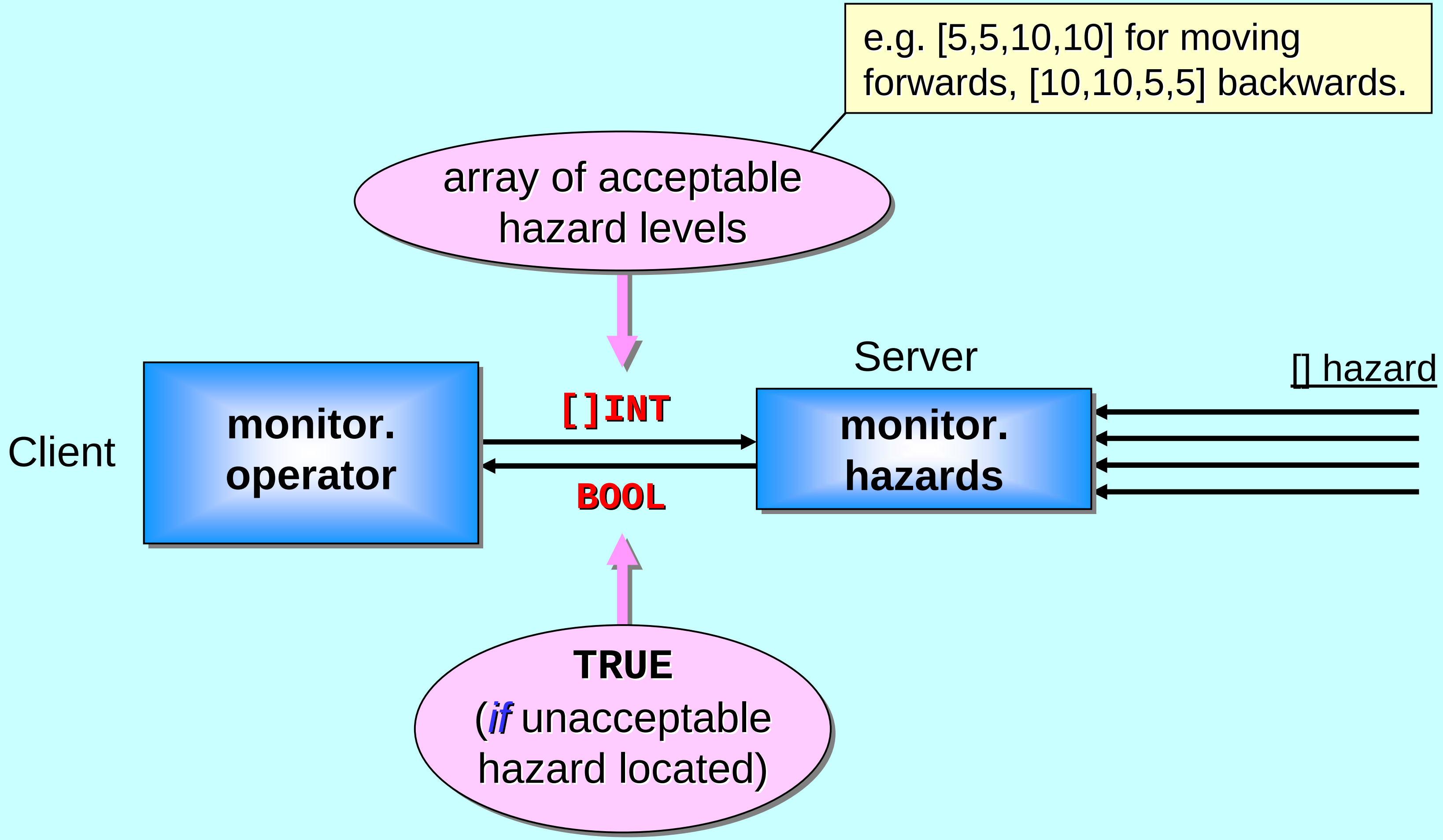
Curiosity on Mars



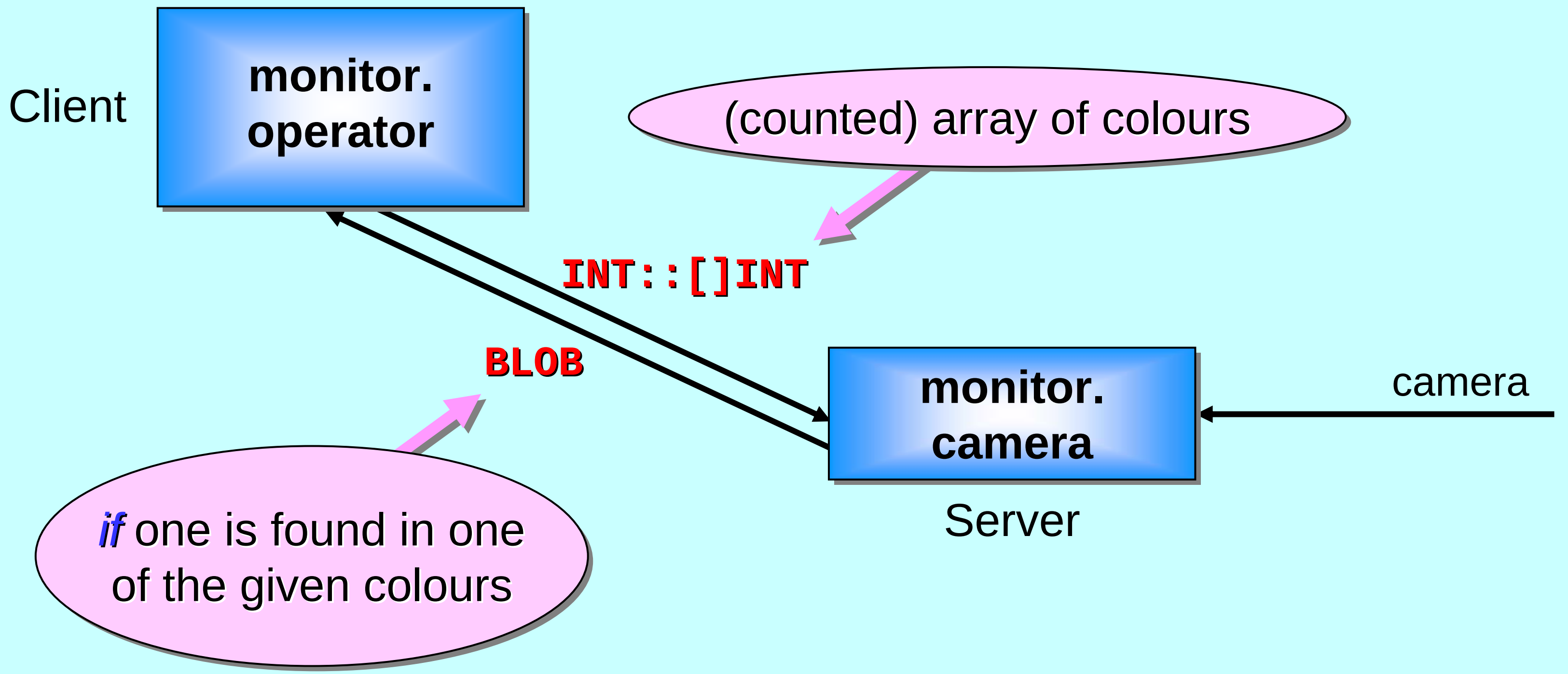
Curiosity on Mars



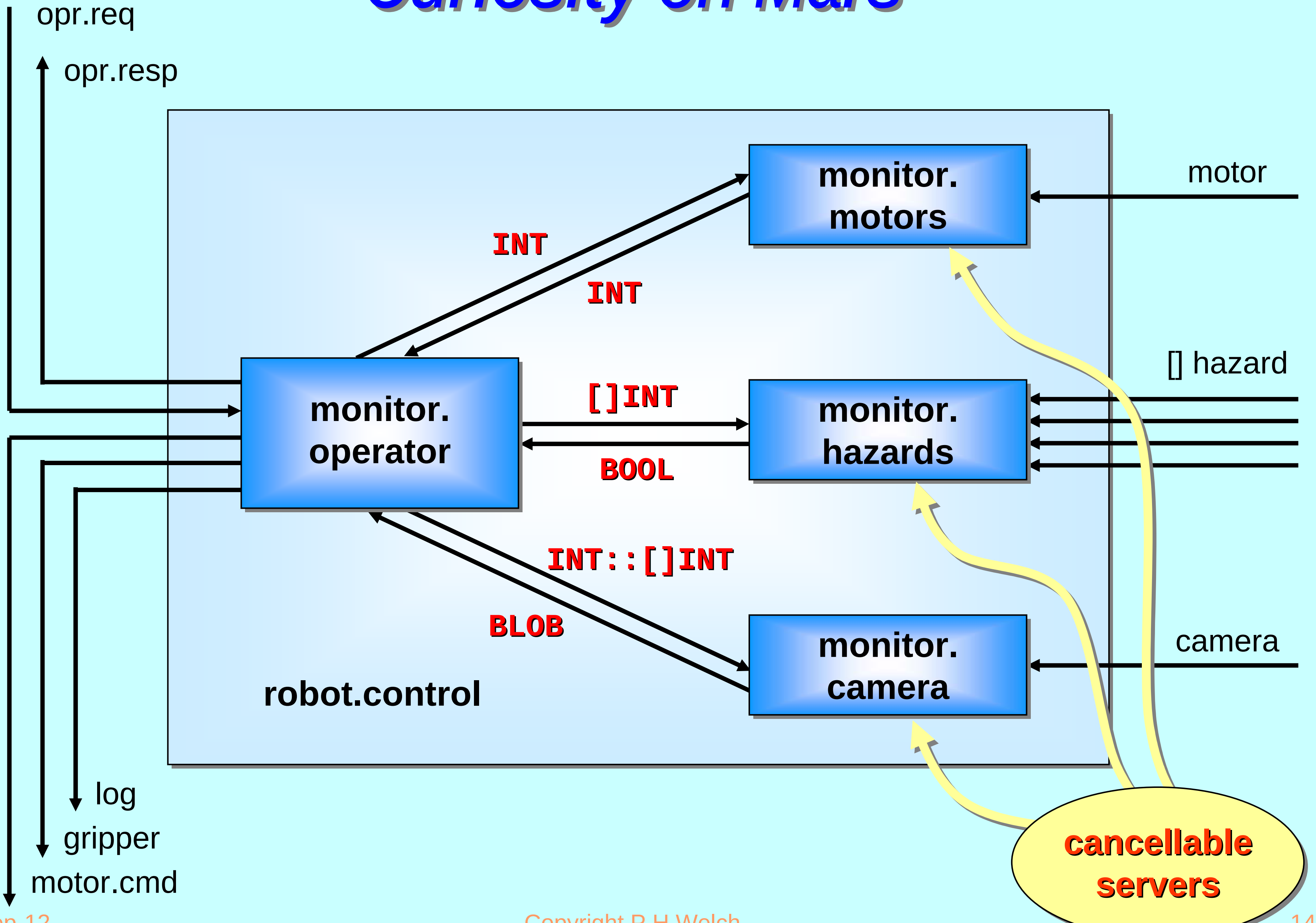
Curiosity on Mars



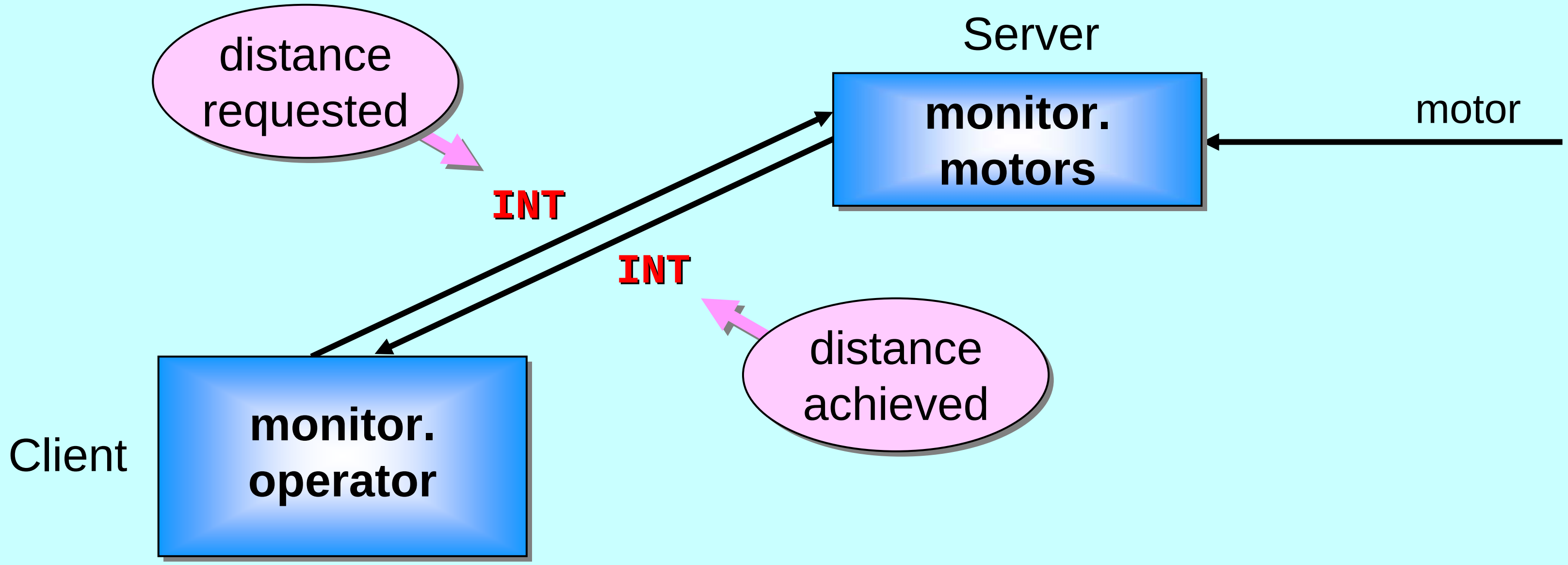
Curiosity on Mars



Curiosity on Mars



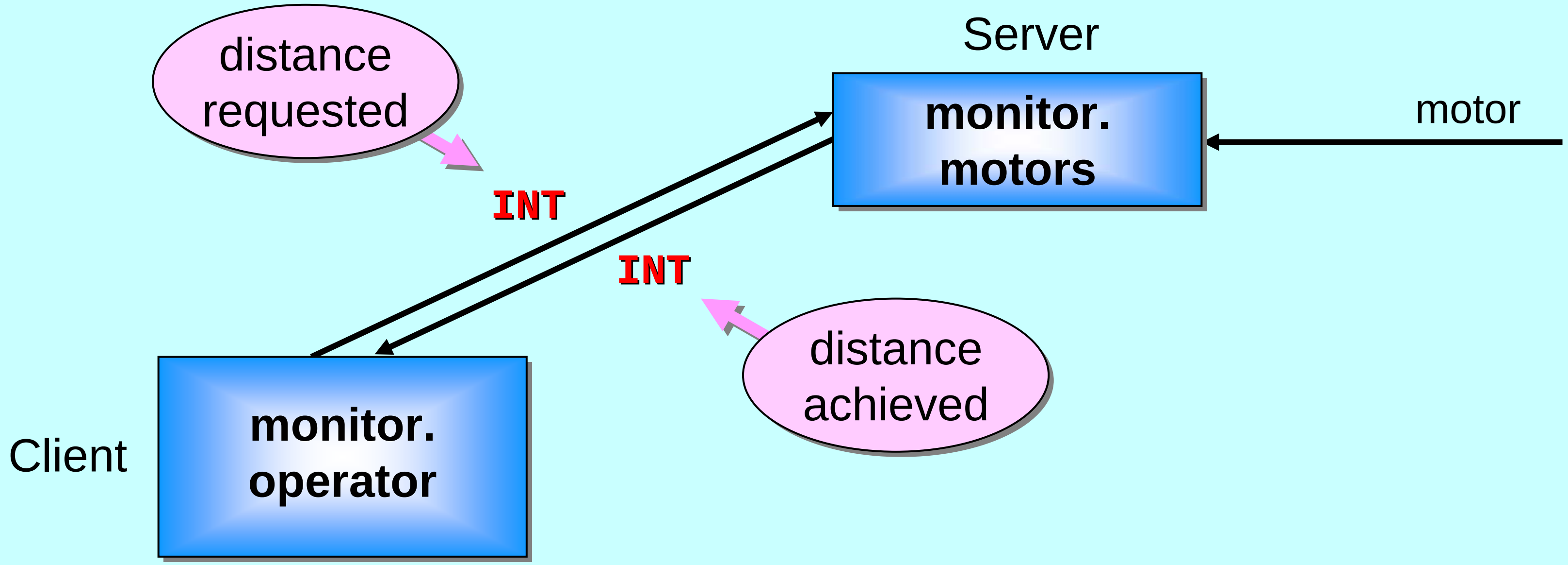
Curiosity on Mars



Normal client-server transaction:

- the client sends a request, then waits for an answer.

Curiosity on Mars



Cancellable client-server transaction:

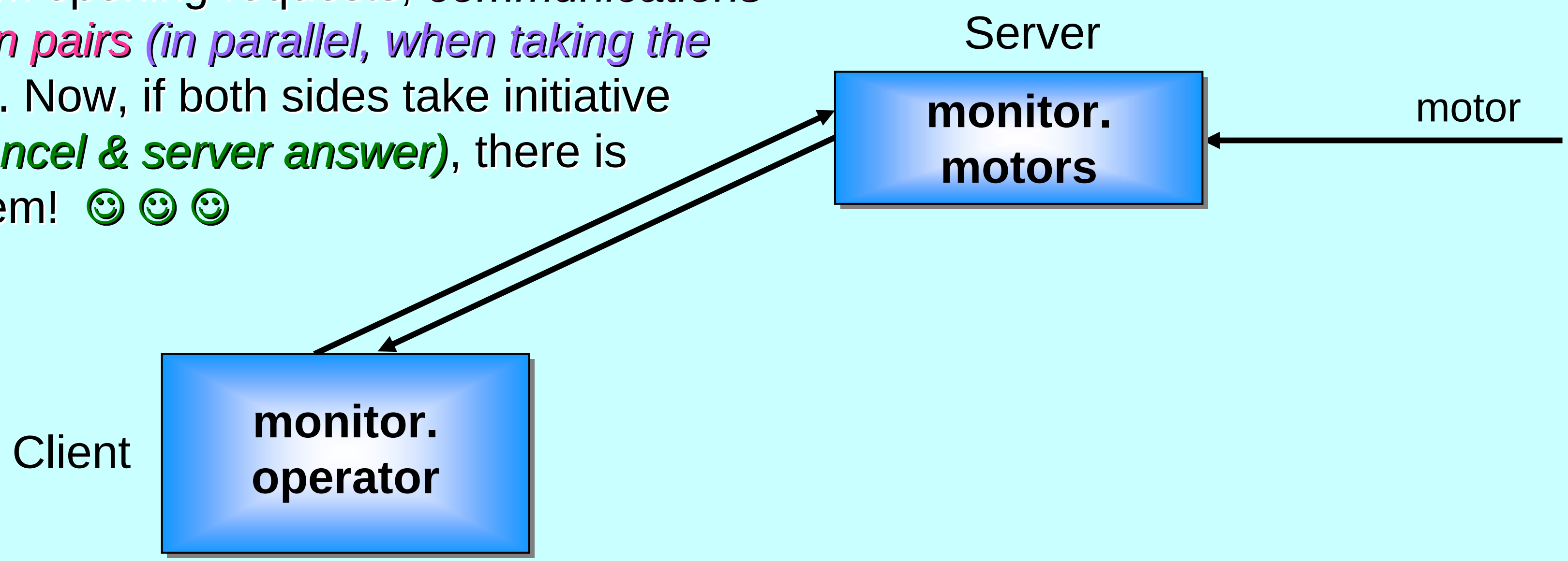
- the client sends a request, then waits for an answer;
- while waiting for an answer, the client may give up and cancel the request.

Problem:

- if the client tries to cancel and the server tries to answer, then deadlock!

Curiosity on Mars

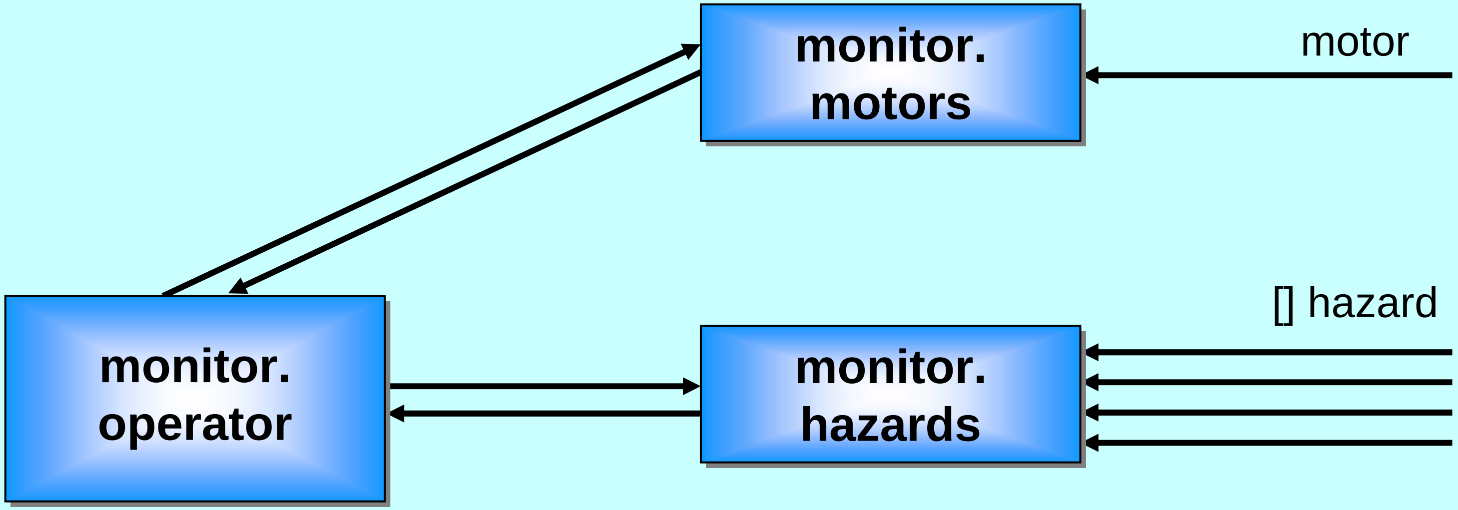
Apart from opening requests, *communications happen in pairs (in parallel, when taking the initiative)*. Now, if both sides take initiative *(client cancel & server answer)*, there is no problem! ☺ ☺ ☺



Solution to cancellable client-server transaction:

- the client sends a *request*, then waits for an *answer*;
  - If an *answer* is received, client sends an *ack* (confirming receipt);
  - to cancel, the client sends a *cancel in parallel* with listening for an *ack*;
    - if an *ack* is received, the request has been cancelled;
    - if an *answer* is received, ignore (server will have seen the *cancel*);
  - to answer, the server sends its *answer in parallel* with listening for an *ack*;
    - if an *ack* is received, server knows client accepted the *answer*;
    - if a *cancel* is received, server knows the service was cancelled.

Curiosity on Mars

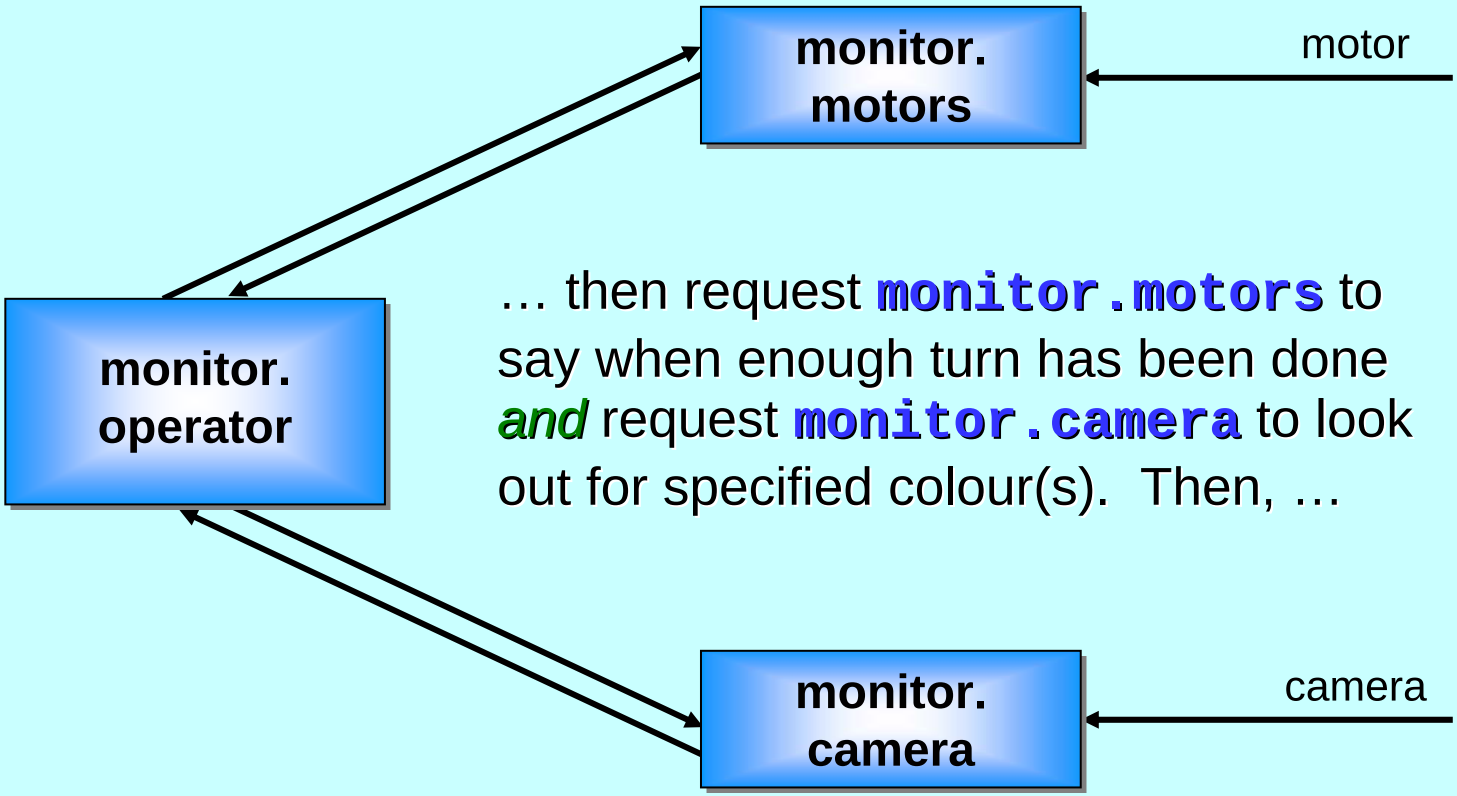


To move robot, first check for hazards (normal client-server transaction). If not clear, don't move. Otherwise, start motors to move robot …

… then request **`monitor.motors`** to say when enough clicks have been seen *and* request **`monitor.hazards`** to look out for specified hazards. Listen to both servers for answers. Whoever answers first, cancel the other!

Curiosity on Mars

To find a blob, start motors to turn robot …



… then request **`monitor.motors`** to say when enough turn has been done *and* request **`monitor.camera`** to look out for specified colour(s). Then, …

… listen to both servers for answers. Whoever answers first, cancel the other!

Implement and Verify …

occam-π²

Curiosity on Mars


```
PROTOCOL ASK
  CASE
    ask, INT              -- target sought
    cancel
    ans.ack
:
```

```
PROTOCOL ANS
  CASE
    ans, INT              -- target found
    cancel.ack, INT       -- target best effort
:
```

Curiosity on Mars

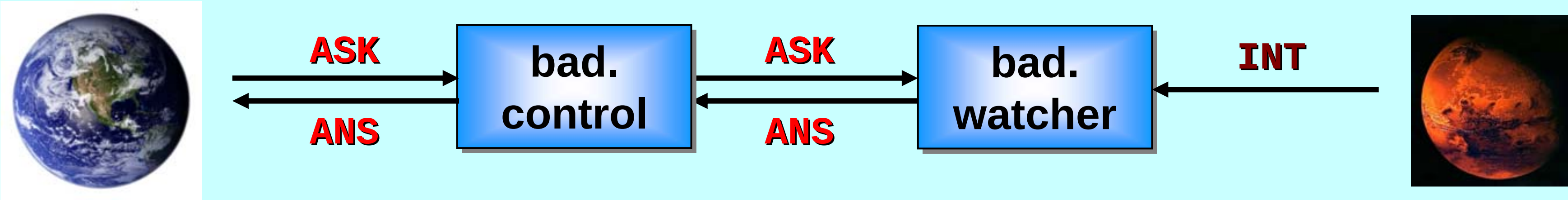

```
PROC simple.watcher (CHAN ASK in?, CHAN ANS out!,
                     CHAN INT data?)
  WHILE TRUE
    PRI ALT
      INT target:
      in ? ask; target                   -- service requested
        INT d:
        SEQ
          data ? d
          WHILE d <> target
            data ? d                     -- monitor and check
          out ! ans; target
      INT d:
      data ? d                           -- monitor and discard
        SKIP
:
```

Curiosity on Mars

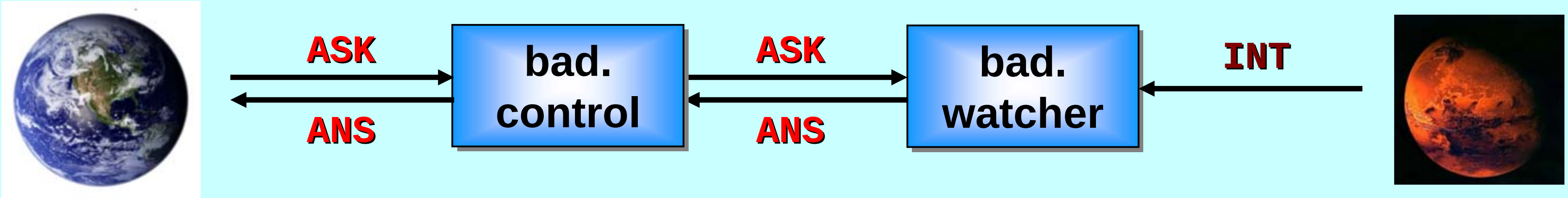
But **simple.watcher** does not deal with a **cancel** request …

First, let's try it the obvious, but wrong, way …

```
PROC bad.watcher (CHAN ASK in?, CHAN ANS out!, CHAN INT data?)
  WHILE TRUE
    PRI ALT
      INT target:
      in ? ask; target                    -- service requested
        INITIAL BOOL serving IS TRUE:
        WHILE serving
          PRI ALT
            in ? cancel                   -- service cancelled
              serving := FALSE
            INT d:
            data ? d                      -- monitor and check
              IF
                d = target
                  SEQ
                    out ! ans; target     -- service result
                    serving := FALSE
                TRUE
                  SKIP
      INT d:
      data ? d                            -- monitor and discard
        SKIP
:
```




```
PROC bad.control (VAL INT timeout, CHAN ASK in?, CHAN ANS out!,
                  CHAN ASK to.server!, CHAN ANS from.server?)
  WHILE TRUE
    TIMER tim:
    INT t, target:
    SEQ
      in ? ask; target                      -- from mission control
      to.server ! ask; target               -- request service
      tim ? t
      ALT
        from.server? ans; target            -- service result
          out ! ans; target                 -- to mission control
        tim ? AFTER t PLUS timeout
          SEQ                               -- (or PAR)
            to.server ! cancel              -- cancel service
            out ! ans; -1                   -- to mission control
:
```




```
PROC bad.system (VAL INT timeout, CHAN ASK in?, CHAN ANS out!,
                 CHAN INT data?)
  CHAN ASK to.server:
  CHAN ANS from.server:
  PAR
    bad.control (timeout, in?, out!, to.server!, from.server?)
    bad.watcher (to.server?, from.server!, data?)
:
```

But …

```
VERIFY LIVELOCK.FREE bad.system          -- reassuring

VERIFY NOT DEADLOCK.FREE bad.system      -- expected, ☺
```

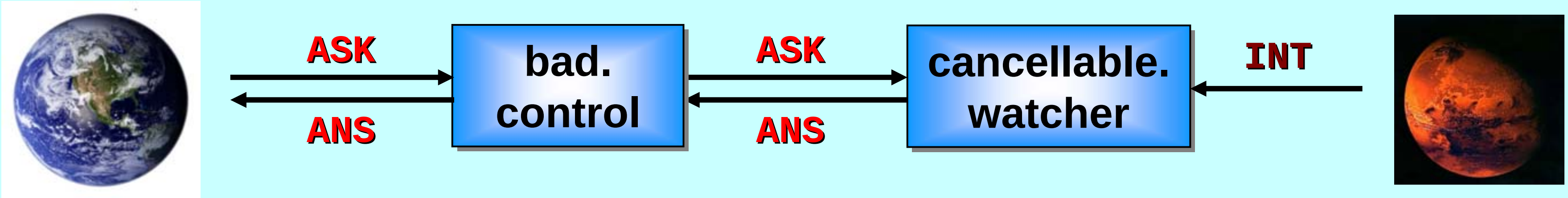
Curiosity on Mars

Let’s do it right …

```
PROC cancellable.watcher (CHAN ASK in?, CHAN ANS out!,
                          CHAN INT data?)
  WHILE TRUE
    PRI ALT
      INT target:
      in ? ask; target                  -- service requested
        INITIAL BOOL serving IS TRUE:
        WHILE serving
          PRI ALT
            ...  deal with service cancellation
            ...  deal with sensor data
      INT d:
      data ? d                          -- monitor and discard
        SKIP
:
```

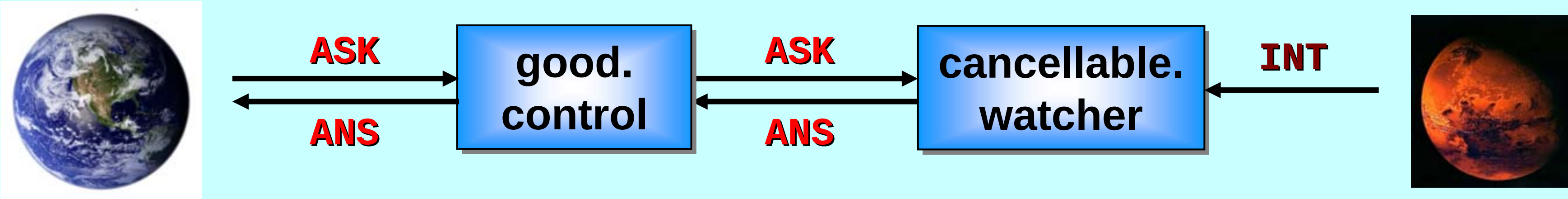
```
{{{  deal with service cancellation
in ? cancel                             -- service cancelled
  SEQ
    out ! cancel.ack; target            -- acknowledge cancel
    serving := FALSE
}}}
```

```
{{{  deal with sensor data
INT d:
data ? d                              -- monitor and check
  IF
    d = target
      SEQ
        PAR
          out ! ans; target           -- service result
          in ? CASE
            ans.ack                   -- result accepted
              SKIP
            cancel                    -- result 'ignored'
              SKIP
        serving := FALSE
    TRUE
      SKIP
}}}
```




```
PROC bad.control (VAL INT timeout, CHAN ASK in?, CHAN ANS out!,
                  CHAN ASK to.server!, CHAN ANS from.server?)
  WHILE TRUE
    TIMER tim:
    INT t, target:
    SEQ
      in ? ask; target                      -- from mission control
      to.server ! ask; target               -- request service
      tim ? t
      ALT
        from.server? ans; target            -- service result
          out ! ans; target                 -- to mission control
        tim ? AFTER t PLUS timeout
          SEQ                               -- (or PAR)
            to.server ! cancel              -- cancel service
            out ! ans; -1                   -- to mission control
:
```

```
PROC good.control (VAL INT timeout, CHAN ASK in?, CHAN ANS out!,
                   CHAN ASK to.server!, CHAN ANS from.server?)
  WHILE TRUE
    TIMER tim:
    INT t, target:
    SEQ
      in ? ask; target                  -- from mission control
      to.server ! ask; target           -- forward request
      tim ? t
      ALT
        from.server? ans; target        -- service result
          SEQ                           -- (or PAR)
            to.server ! ans.ack         -- acknowledge result
            out ! ans; target           -- to mission control
        tim ? AFTER t PLUS timeout
          SEQ                           -- (cannot be PAR)
            PAR
              to.server ! cancel        -- cancel service
              from.server ? CASE
                ans; target             -- accept as acknowledge
                  SKIP
                cancel.ack; target      -- actual acknowledge
                  SKIP
            out ! ans; target           -- to mission control
:
```




```
PROC good.system (VAL INT timeout, CHAN ASK in?, CHAN ANS out!,
                  CHAN INT data?)
  CHAN ASK to.server:
  CHAN ANS from.server:
  PAR
    good.control (timeout, in?, out!, to.server!, from.server?)
    cancellable.watcher (to.server?, from.server!, data?)
:
```

And …

```
VERIFY LIVELOCK.FREE good.system        -- reassuring

VERIFY DEADLOCK.FREE good.system        -- gotcha ☺ ☺ ☺
```

Curiosity on Mars

Recall …

The exercise is to design and implement an autonomous **`robot.control`** process for a rover vehicle on Mars.

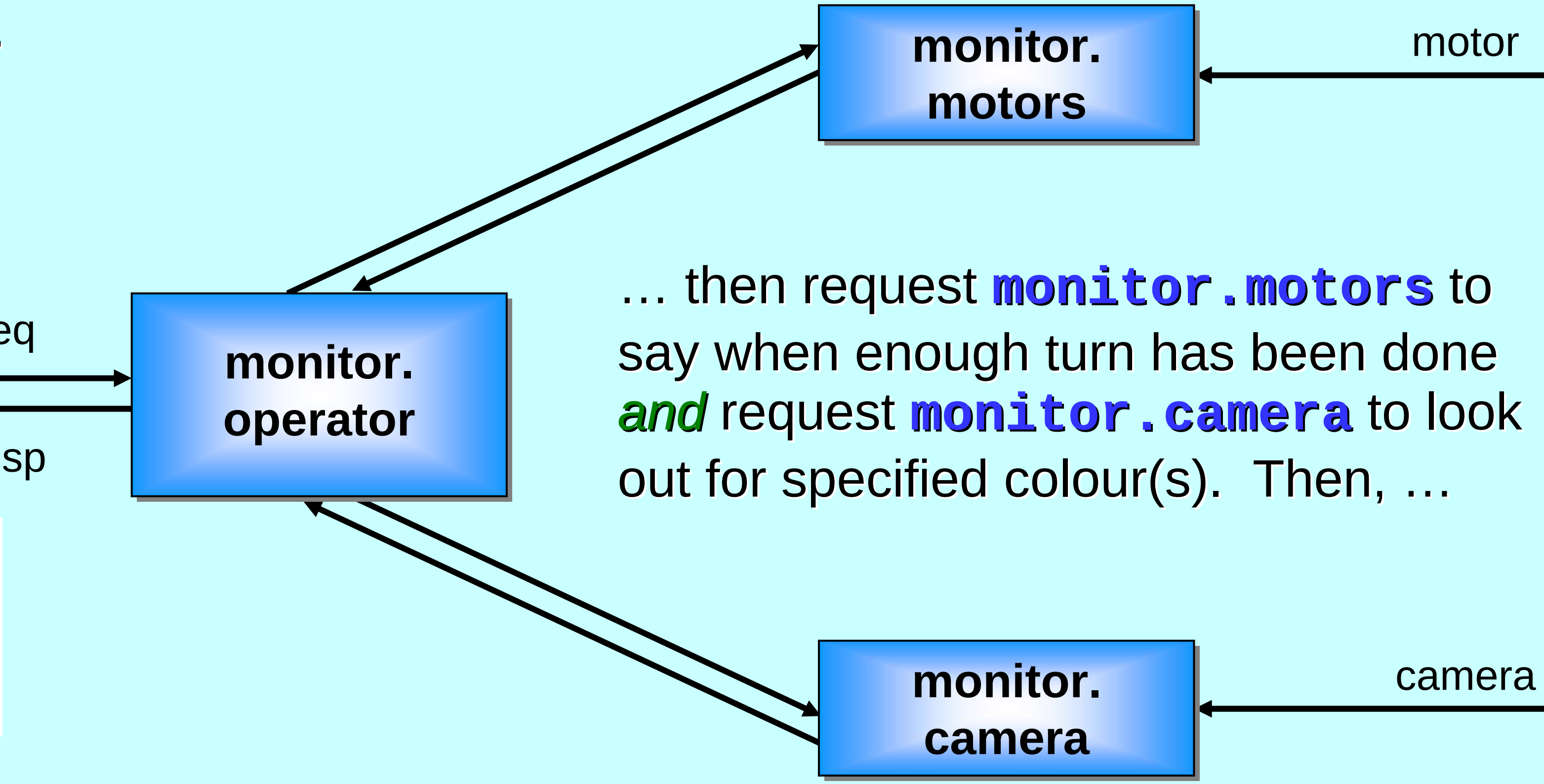
The controller has to respond to commands from its operator back on Earth, to operate simple actuators (start/stop motors, deploy gadgets) and to monitor and respond appropriately to input from peripherals (motor feedback clicks, raw echo sensor data, processed camera images).

The controller must not deadlock … or have a sub-system deadlock …

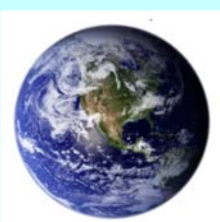
For Curiosity (or any autonomous vehicle), the verification is not yet sufficient … we need to verify that *multiple* cancellable servers do not cause problems …

Curiosity on Mars

To find a blob, start motors to turn robot …



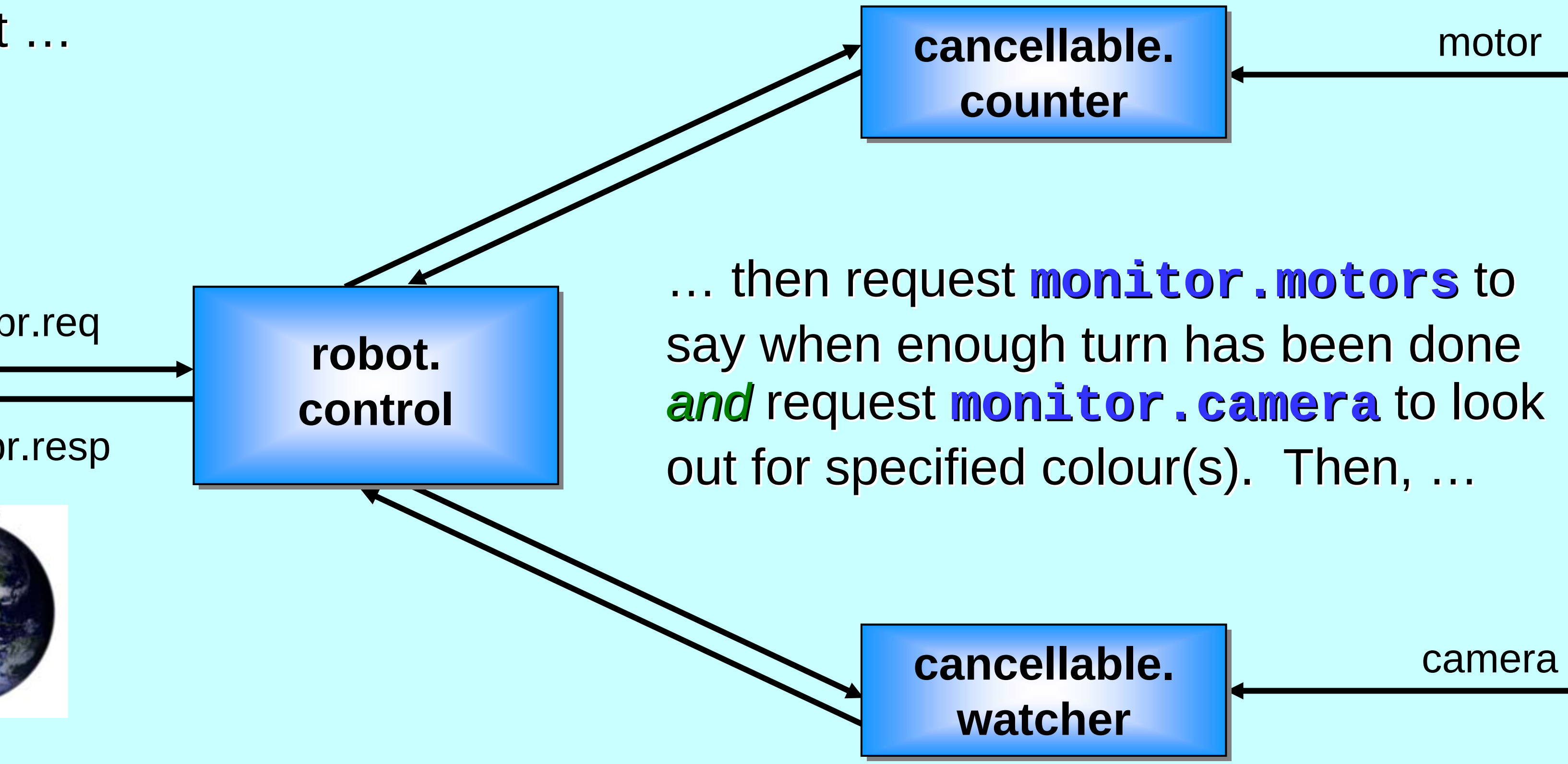
… then request **`monitor.motors`** to say when enough turn has been done *and* request **`monitor.camera`** to look out for specified colour(s). Then, …



… listen to both servers for answers. Whoever answers first, cancel the other!

Curiosity on Mars

To find a blob, start motors to turn robot …

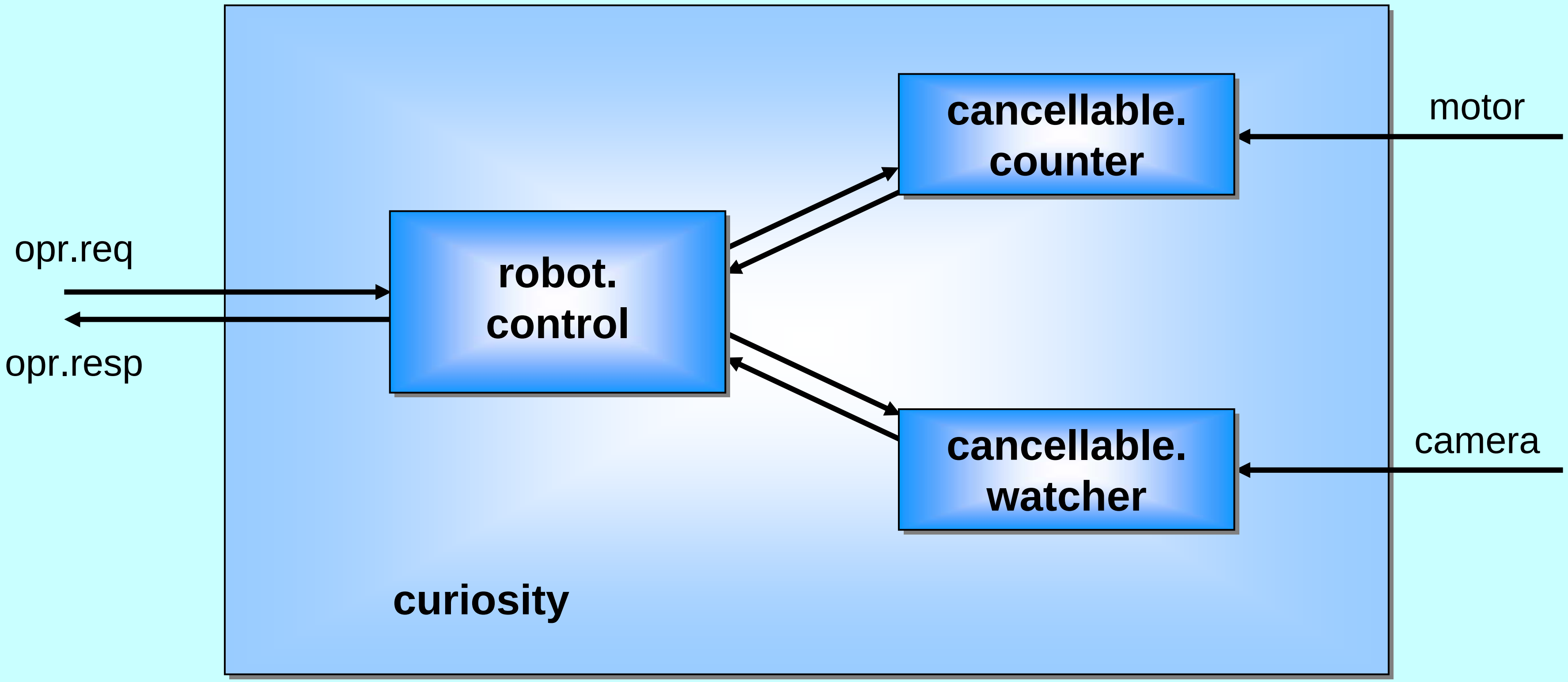


… then request **`monitor.motors`** to say when enough turn has been done *and* request **`monitor.camera`** to look out for specified colour(s). Then, …

… listen to both servers for answers. Whoever answers first, cancel the other!

Just changing the names …

Curiosity on Mars

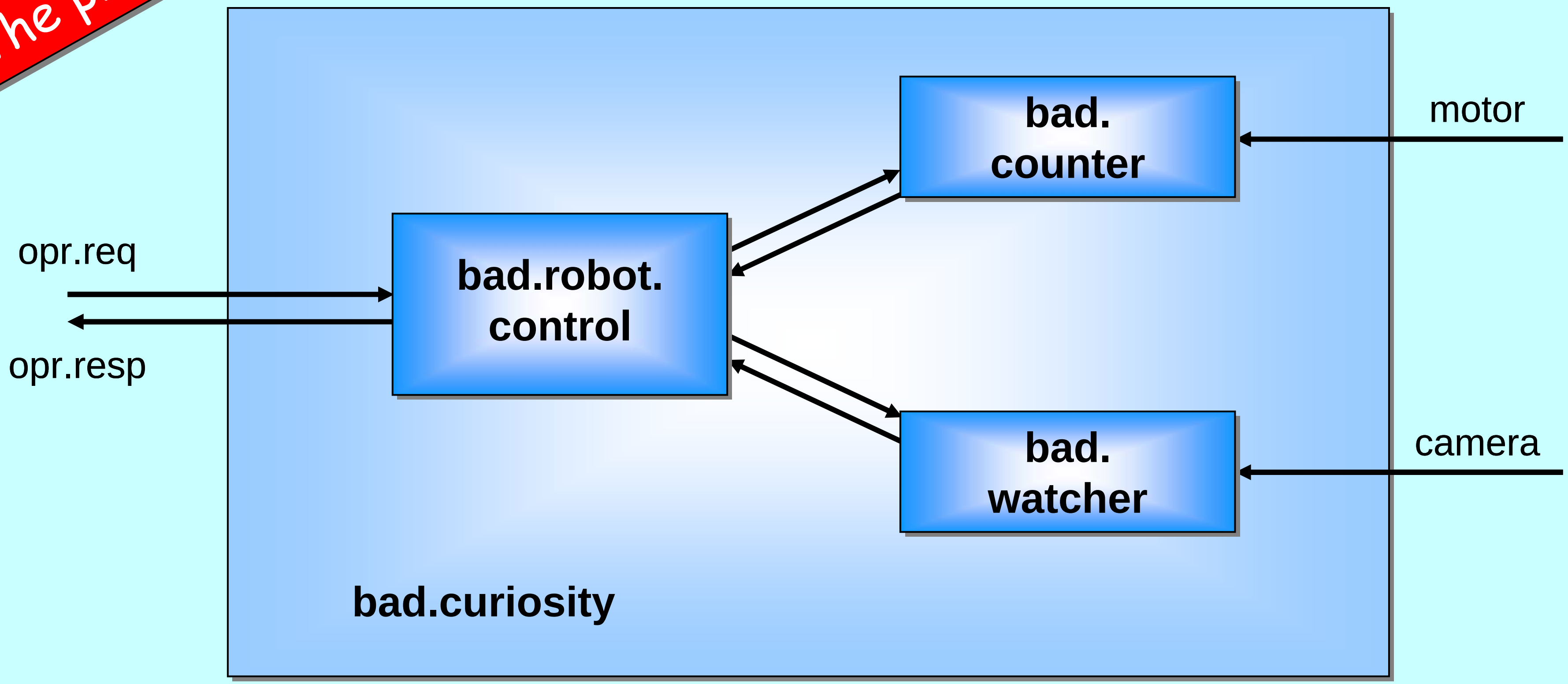



```
VERIFY LIVELOCK.FREE curiosity            -- reassuring

VERIFY DEADLOCK.FREE curiosity            -- not enough !!!
```

The problem is …

Curiosity on Mars

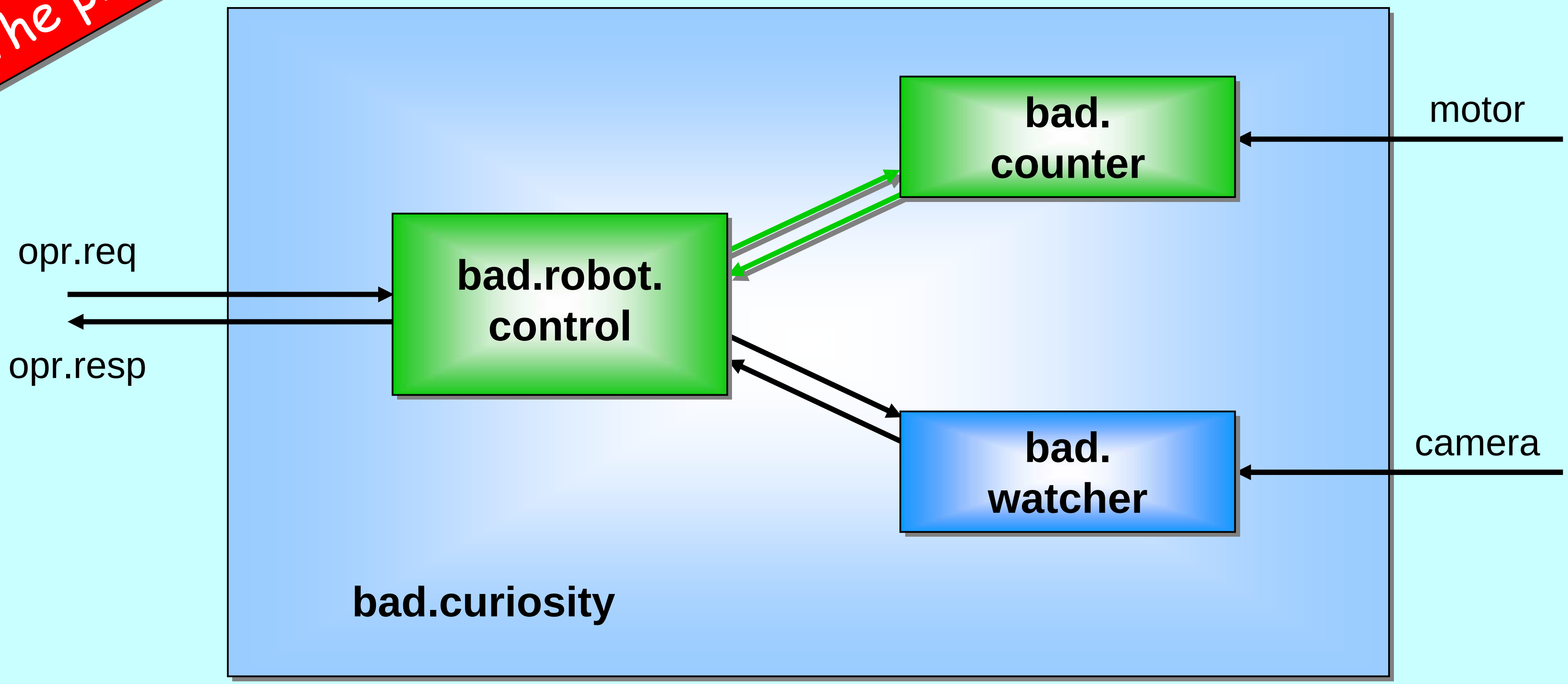



```
VERIFY LIVELOCK.FREE bad.curiosity      -- reassuring

VERIFY DEADLOCK.FREE bad.curiosity      -- surprise !!! ☹ ☹ ☹
```


The problem is …

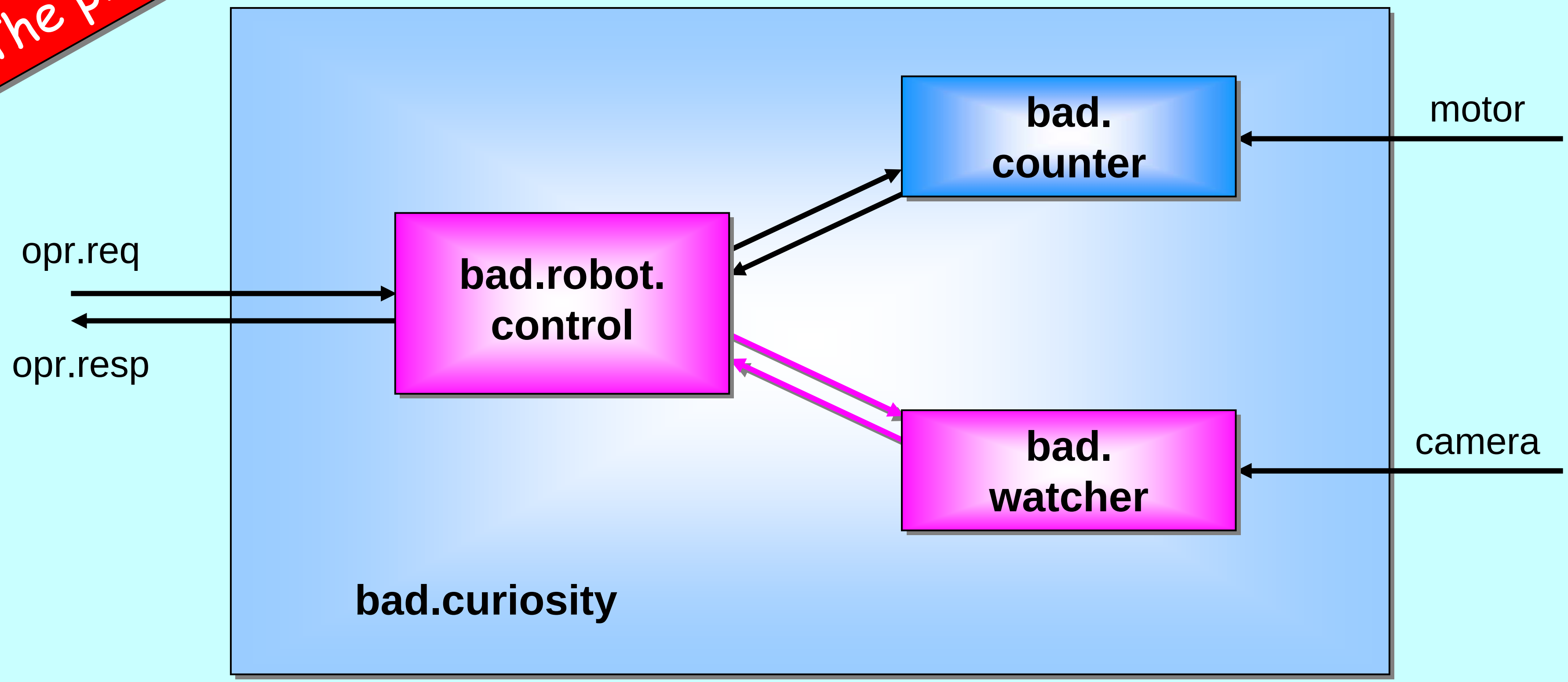
Curiosity on Mars



The green sub-system may deadlock, leaving `bad.watcher` still alive (in its outer loop) accepting and discarding camera data forever. So, the system is not deadlocked!

Curiosity on Mars

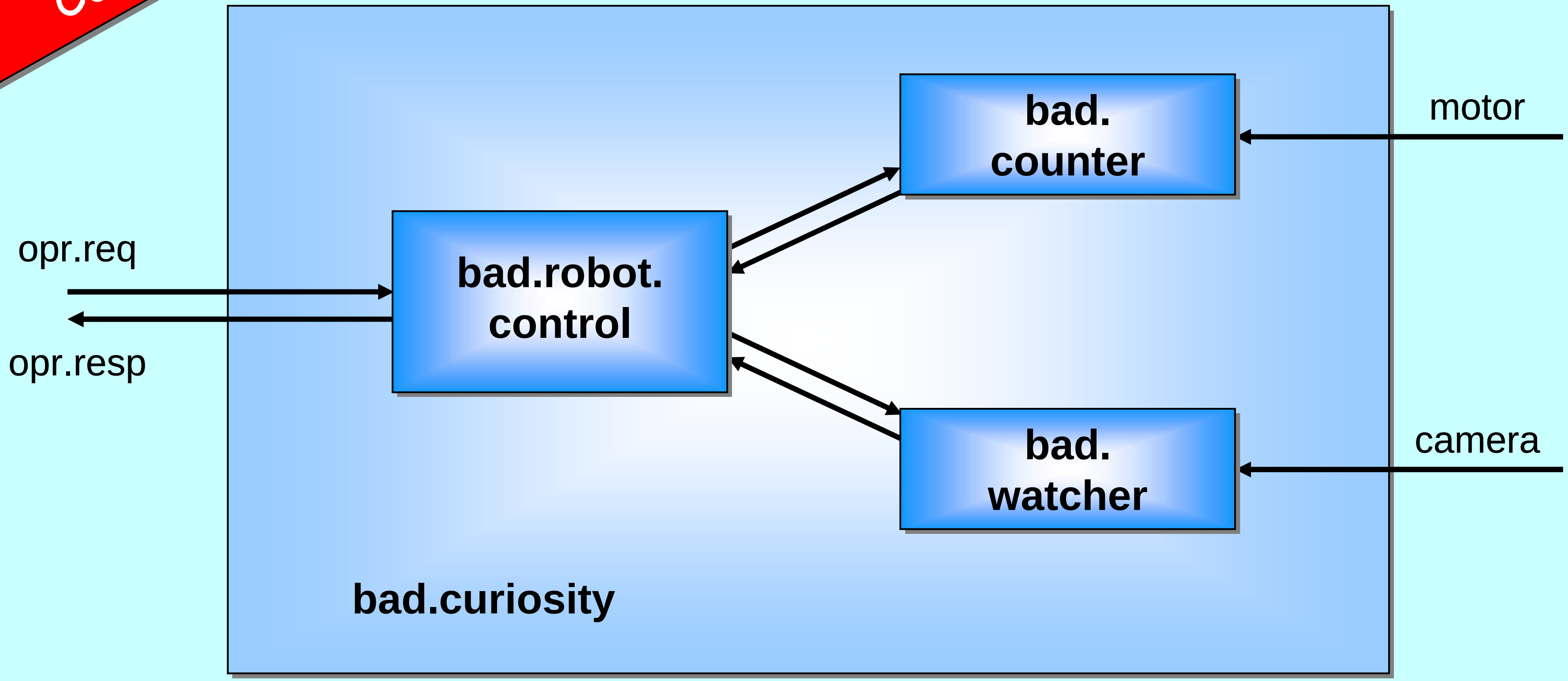
The problem is …



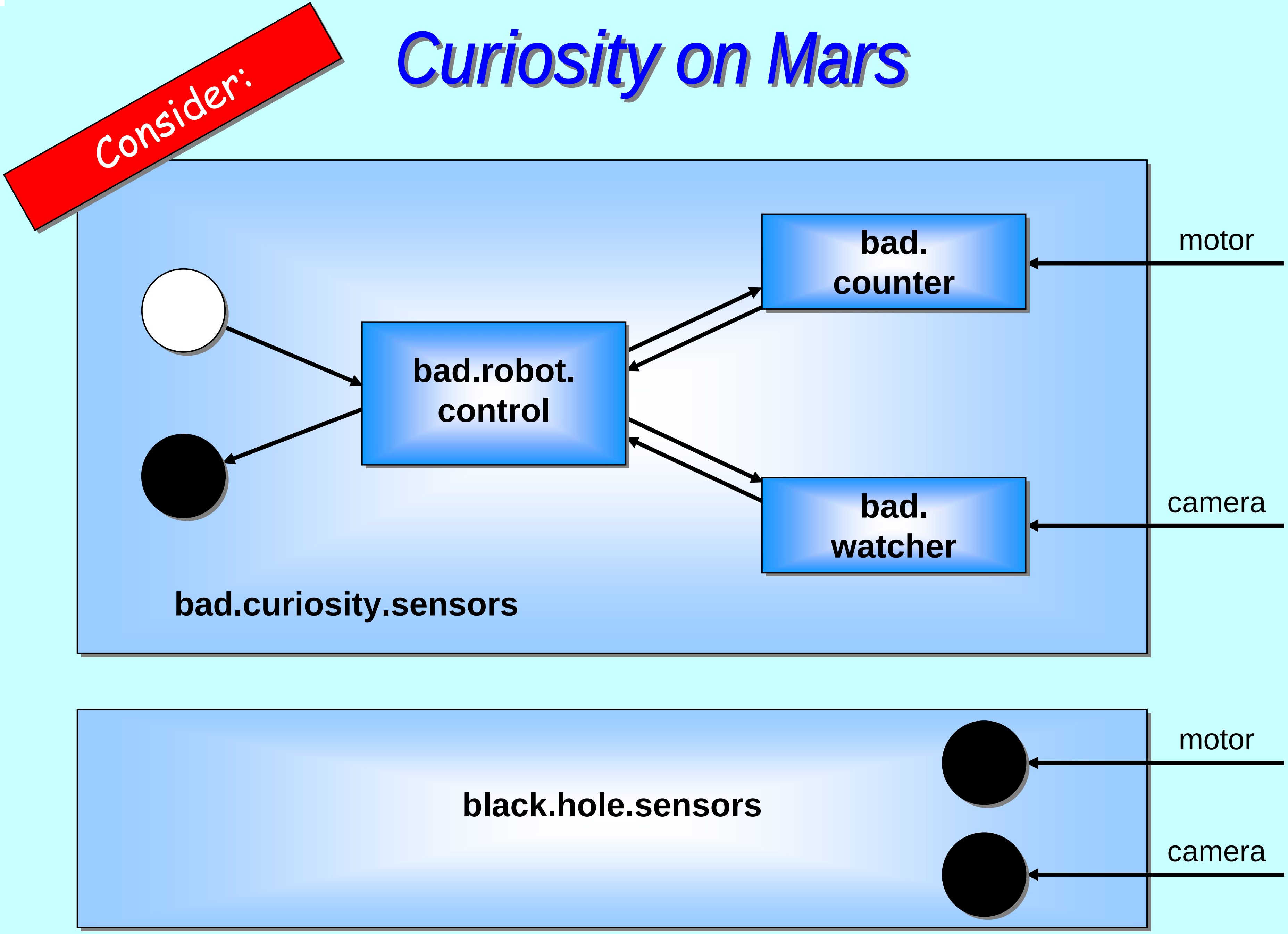
Or the pink sub-system may deadlock, leaving `bad.counter` still alive (in its outer loop) accepting and discarding camera data forever. So, the system is not deadlocked!

Curiosity on Mars

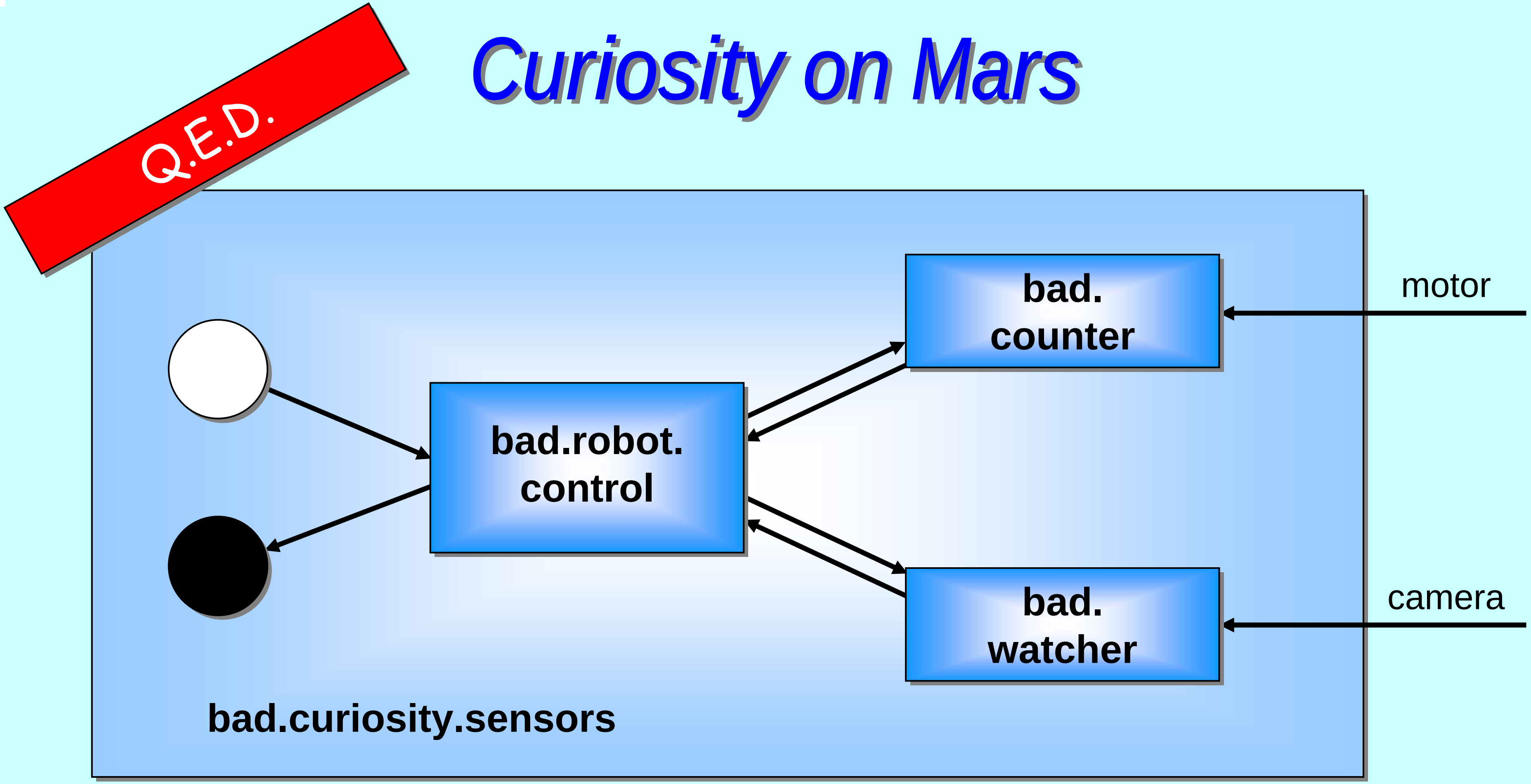
Consider:



Curiosity on Mars



Curiosity on Mars

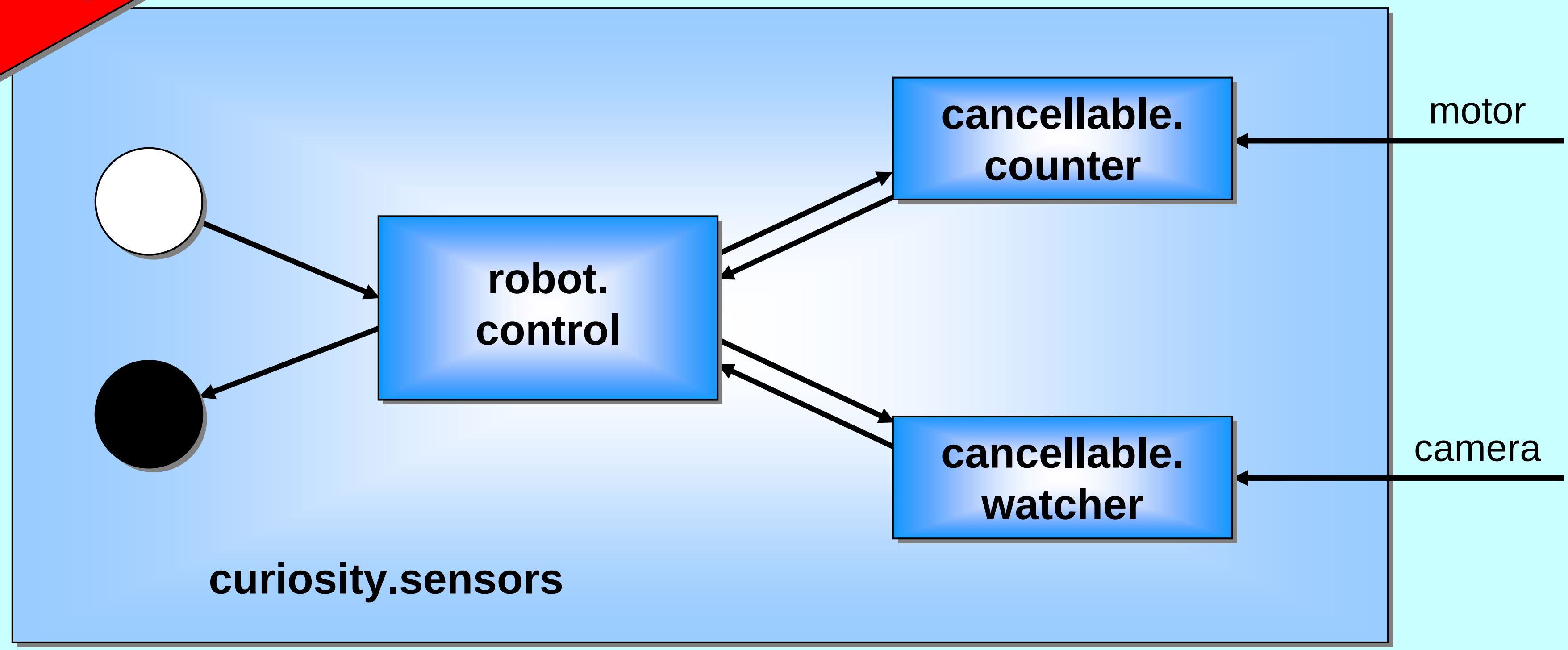



```
VERIFY LIVELOCK.FREE bad.curiosity.sensors          -- reassuring
VERIFY LIVELOCK.FREE black.hole.sensors             -- reassuring

VERIFY NOT bad.curiosity.sensors REFINES.F black.hole.sensors
                                                    -- gotcha !!!
```

Curiosity on Mars

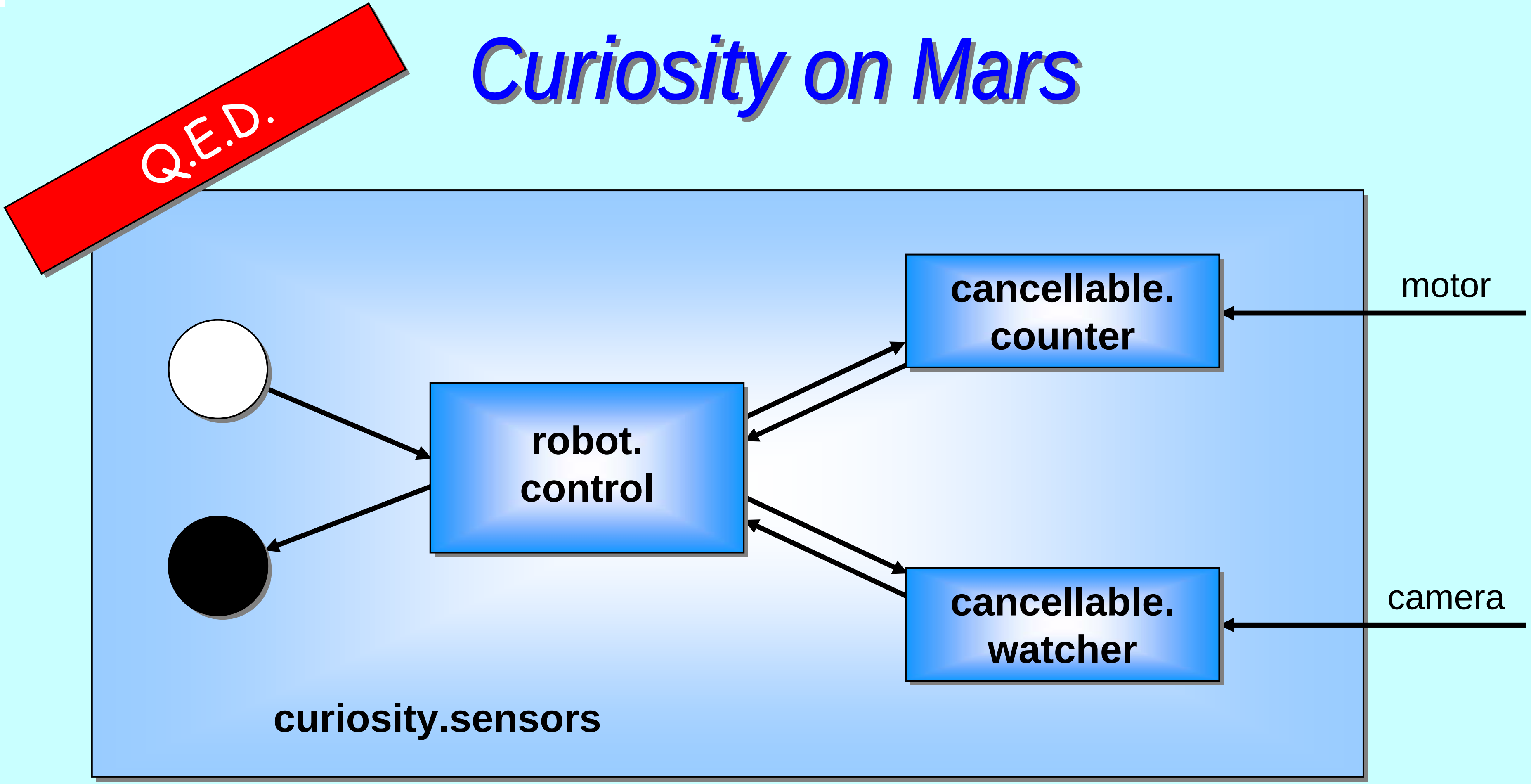
Q.E.D.




```
VERIFY LIVELOCK.FREE good.curiosity.sensors          -- reassuring
VERIFY LIVELOCK.FREE black.hole.sensors              -- reassuring

VERIFY curiosity.sensors REFINES.F black.hole.sensors
                                                     -- gotcha !!!
```

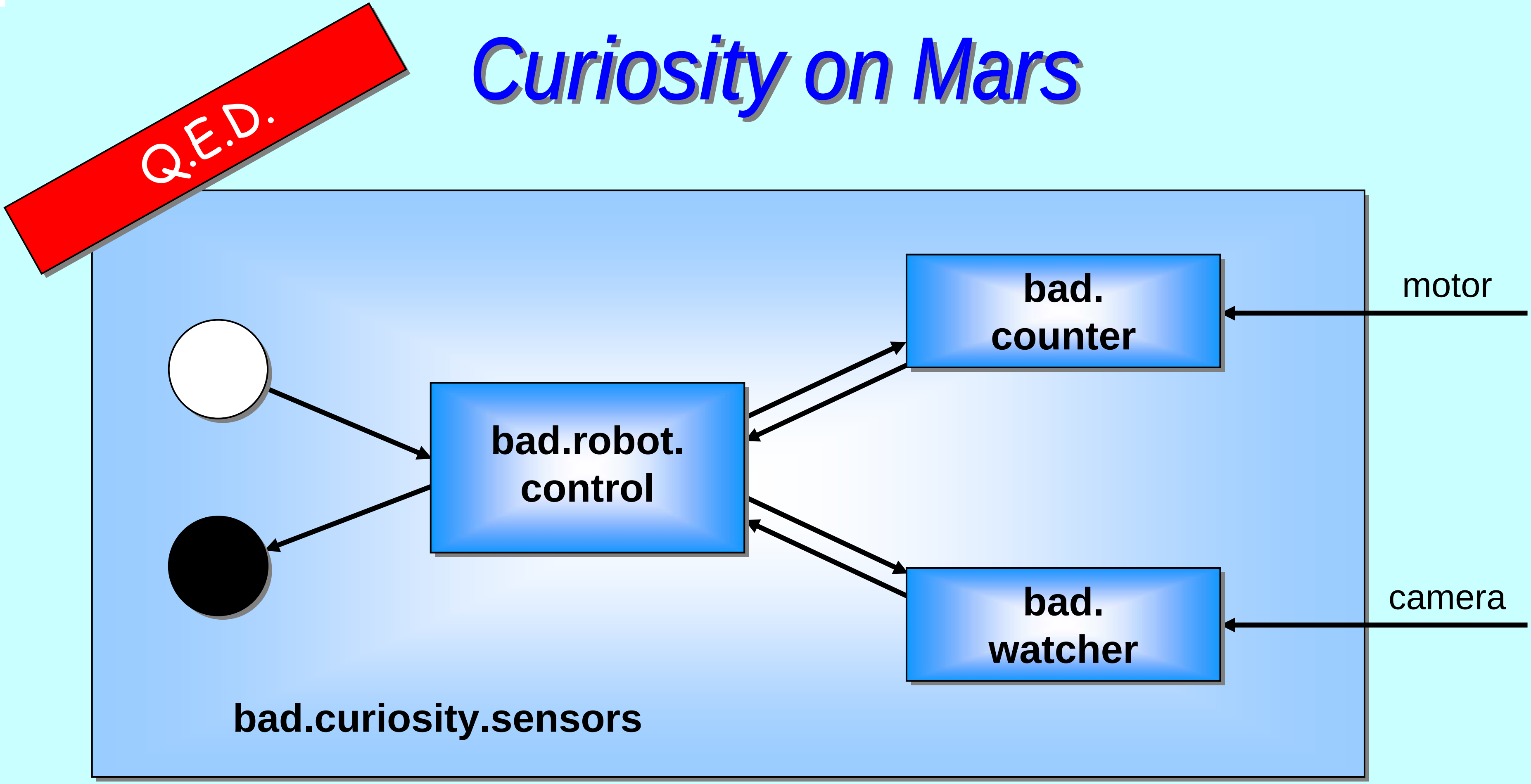
Curiosity on Mars




```
VERIFY curiosity.sensors REFINES.F black.hole.sensors
                                              -- gotcha !!!
```

Now, **black.hole.sensors** never refuses motor or camera. Therefore, neither does **curiosity.sensors** (nor **curiosity**).

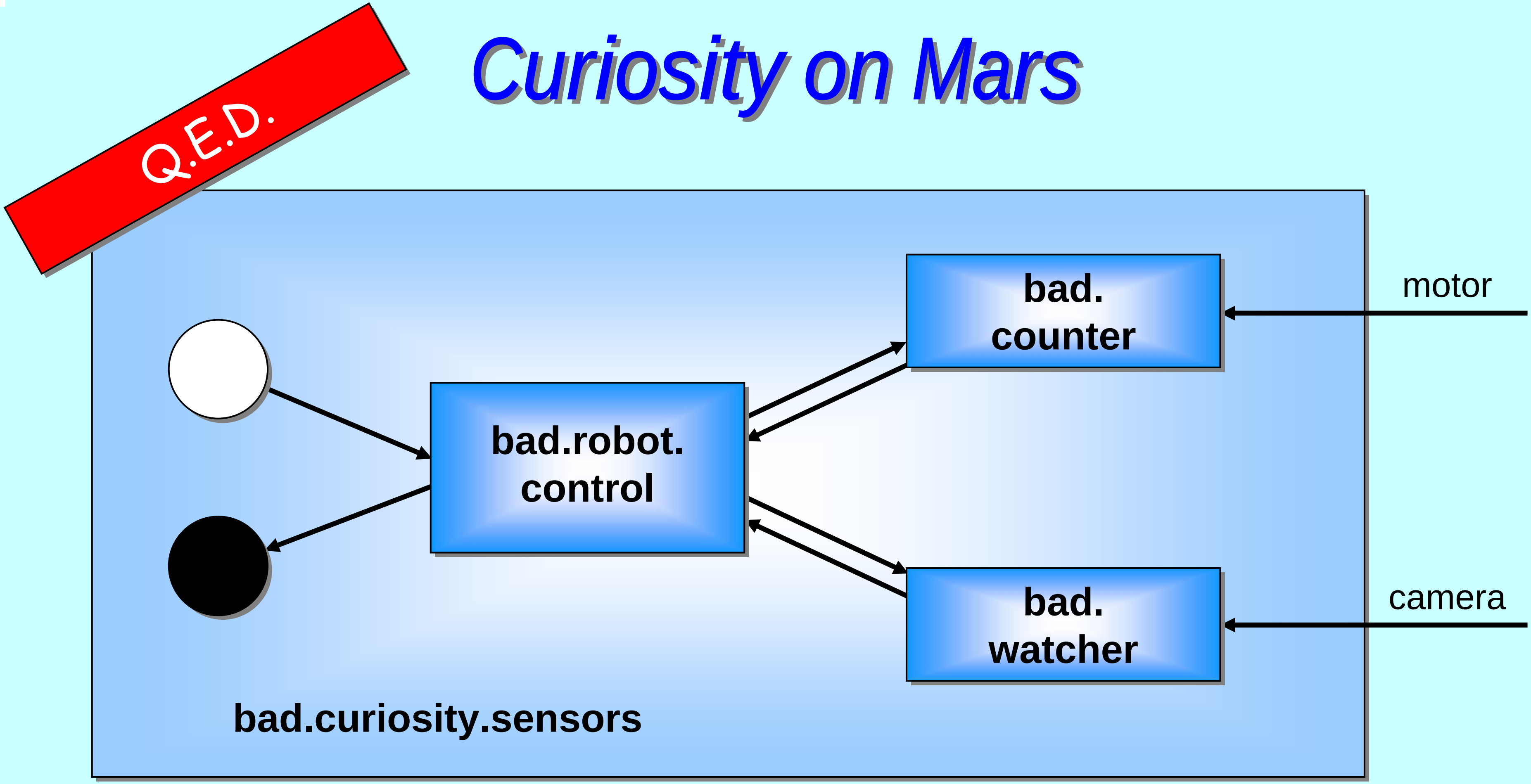
Curiosity on Mars




```
VERIFY NOT bad.curiosity.sensors REFINES.F black.hole.sensors
                                                  -- gotcha !!!
```

Now, **black.hole.sensors** never refuses motor or camera. Therefore, **bad.curiosity.sensors** (and **bad.curiosity**) does.

Curiosity on Mars



Run Other Demo …

Curiosity on Mars

This is a student exercise to design and implement part of the control logic for an autonomous `robot.control` process for a rover vehicle on Mars.

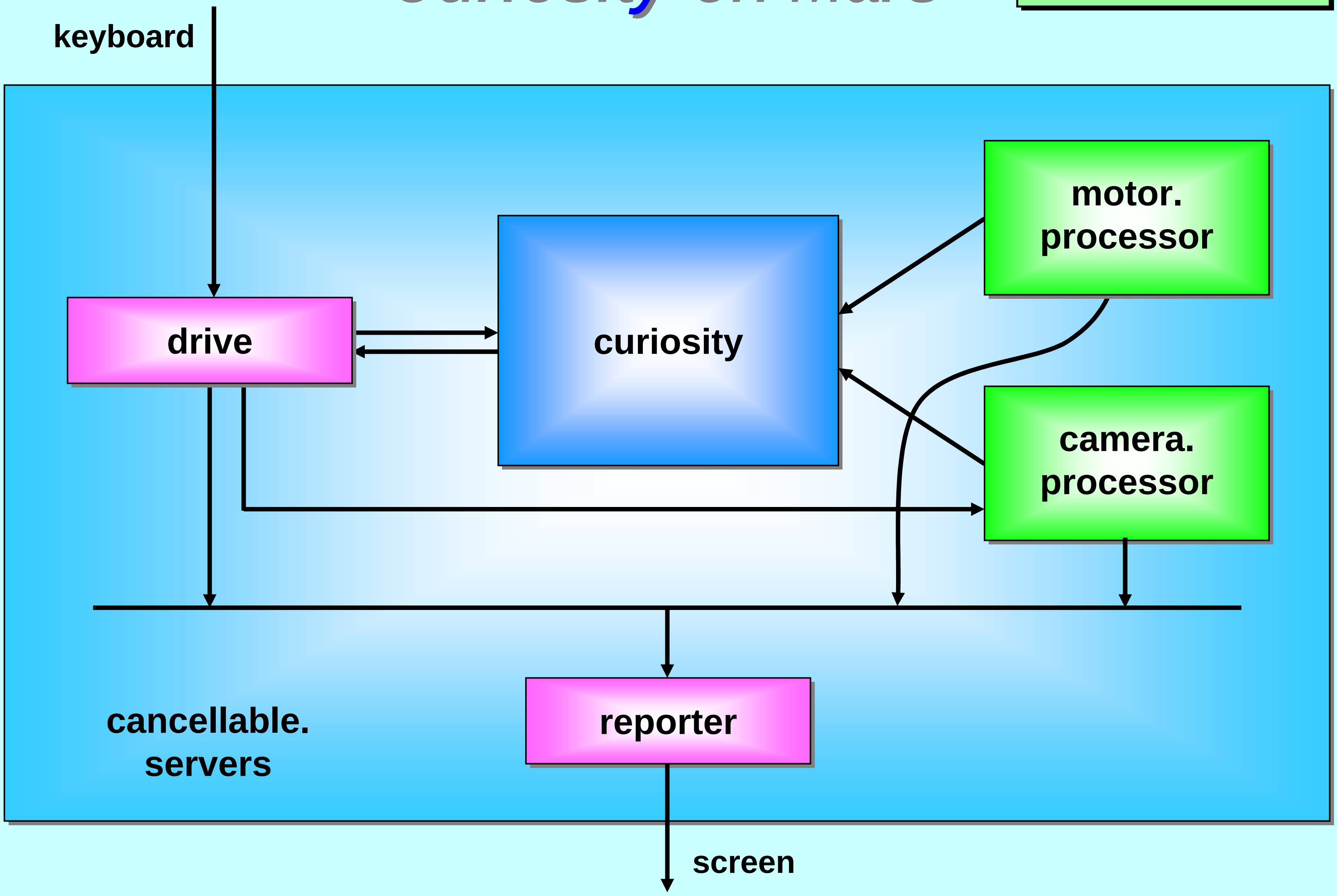
The controller has to respond to commands from its operator back on Earth, to operate simple actuators (start/stop motors, deploy gadgets) and to monitor and respond appropriately to input from peripherals (motor feedback clicks, raw echo sensor data, processed camera images).

The controller must not deadlock … or have a sub-system deadlock …

Run Other Demo …

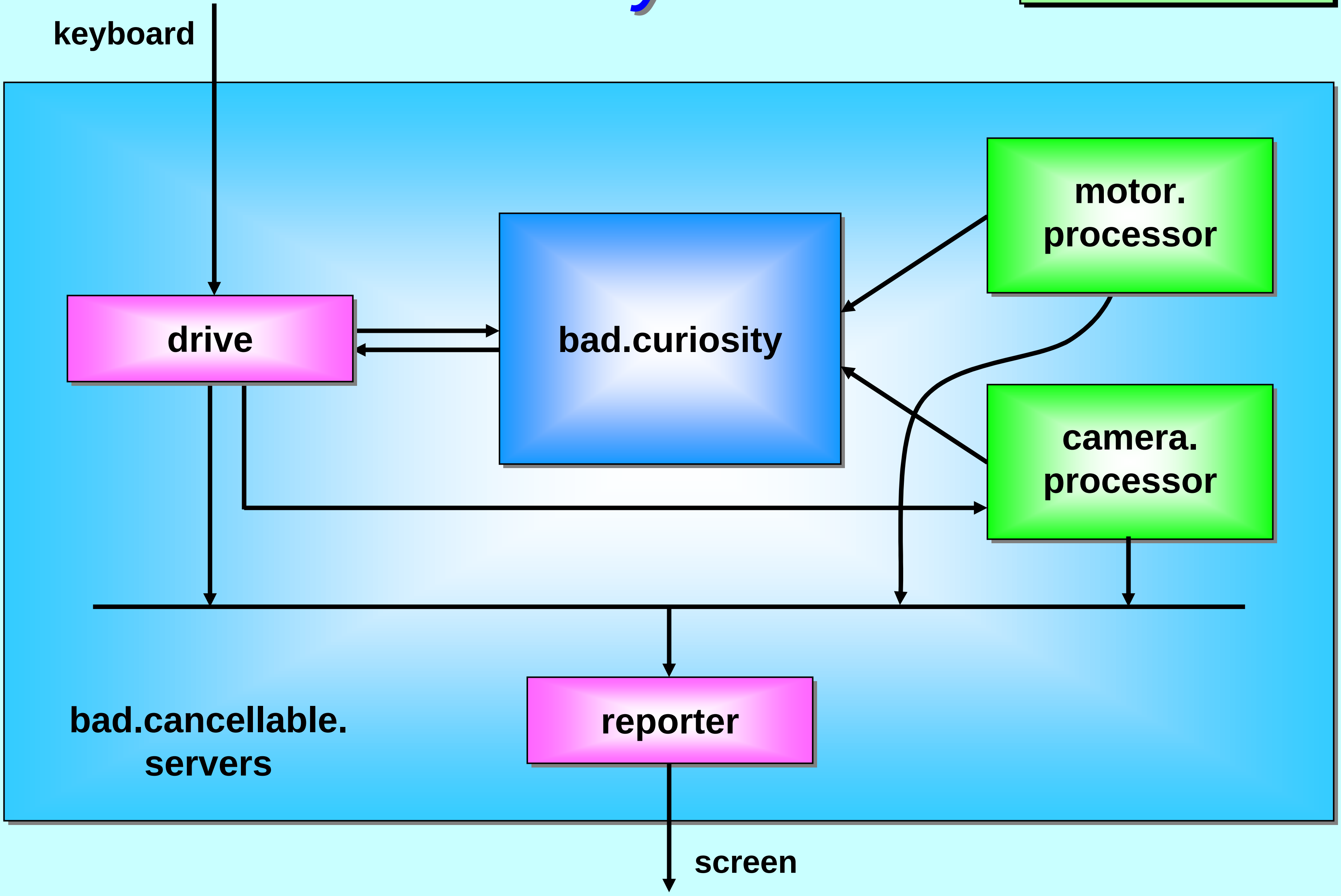
Curiosity on Mars

Other Demo ...



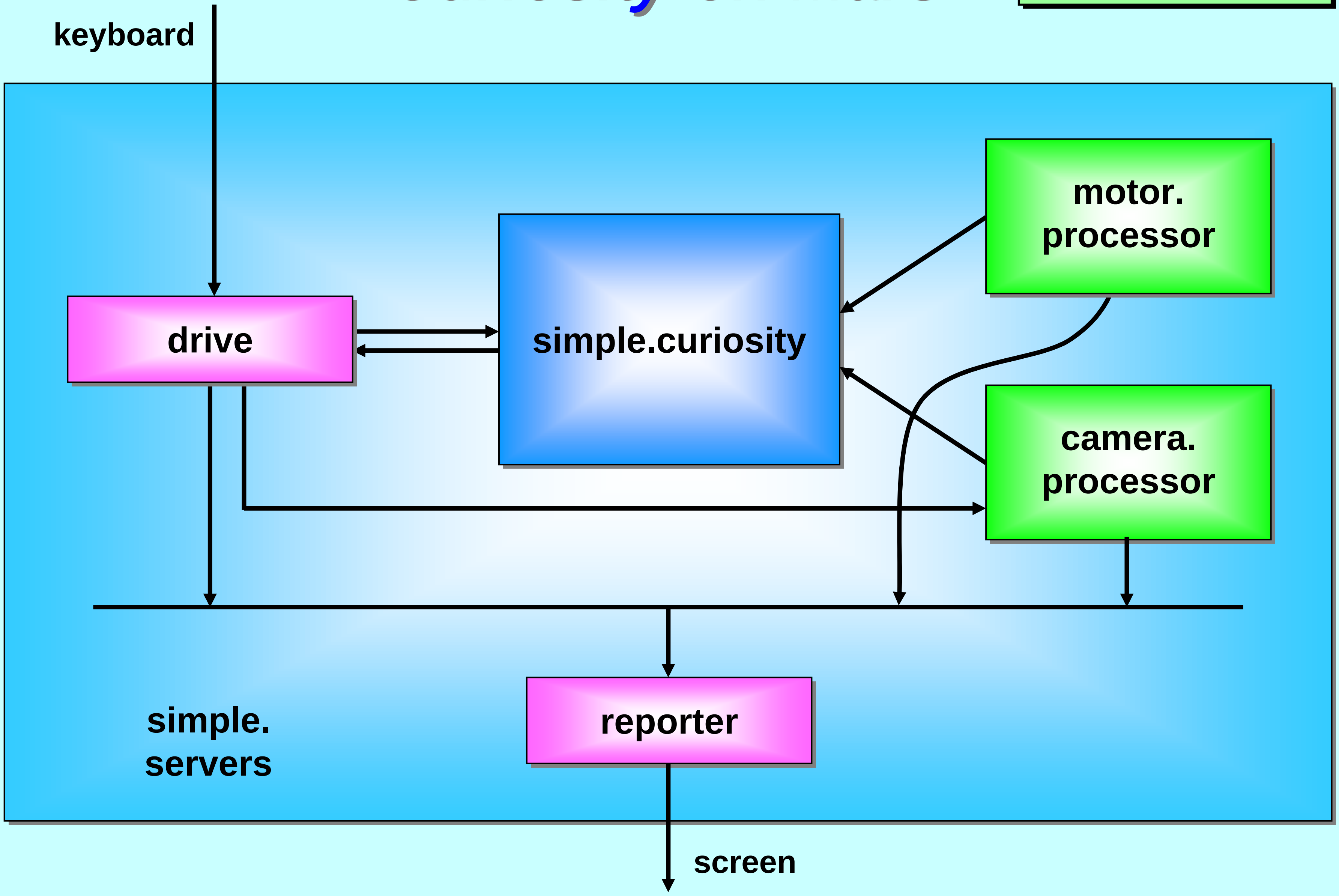
Curiosity on Mars

Other Demo …



Curiosity on Mars

Other Demo …



Curiosity on Mars

Source codes for the system in this presentation is available in 3 forms:

cancellable-servers.op2

occam-π^2 source code (showing generated CSP_m) *

cancellable-servers.csp

CSP_m script (showing occam-π^2 source code) – FDR ready.

cancellable-servers.occ

Executable occam-π source code (with **VERIFY** assertions/**PROC**s commented out) – includes testrig.

* For now, generated by hand …

Curiosity on Mars

This is a student exercise to design and implement part of the control logic for an autonomous **robot.control** process for a rover vehicle on Mars.

Any questions?