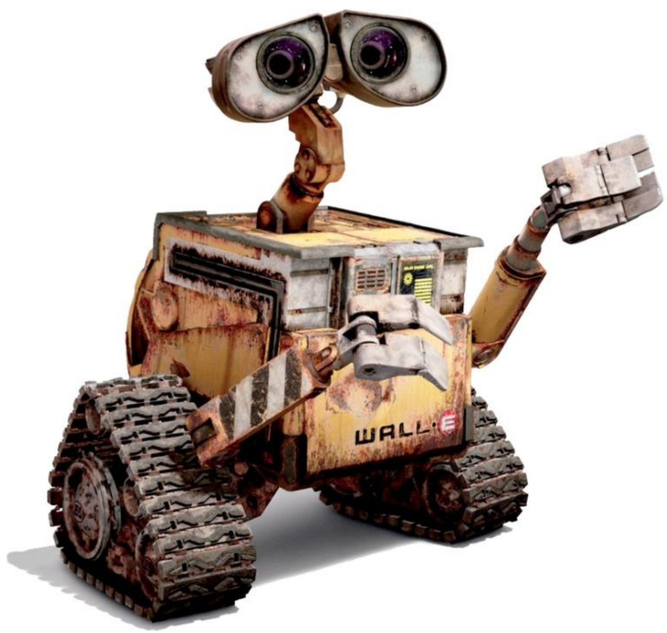
REACT



REACT:
Event-driven
Asynchronous
Concurrent
Turing-complete

Students: Will Noble, Aleksandar Milicevic
Supervisor: Stelios Sidiroglou
PI: Prof. Martin Rinard

Robotics Programming

- Abstraction gap
  - high-level problem, low-level implementation primitives
- Typically steep learning curve, especially for hobbyists
- Programming in terms of low-level primitives is tedious and error-prone
- Largely non-standardized

Distributed, Interactive, Heterogeneous

- Concurrent and distributed architecture
  - data races
  - atomicity
  - deadlocks
  - shared data inconsistency

- Implementation complexity
  - hard to analyze, test, ensure correctness

Proposed Solution

- **Model-based, event-driven paradigm**
  - global model of the entire distribute system
  - simple sequential semantics
  - expressive programming language
- **Runtime environment**
  - manages access to shared state
  - no data races by construction
- **Analyses**
  - amenable to formal analyses (e.g., testing, security, …)

REACT: Records, Contexts, Events

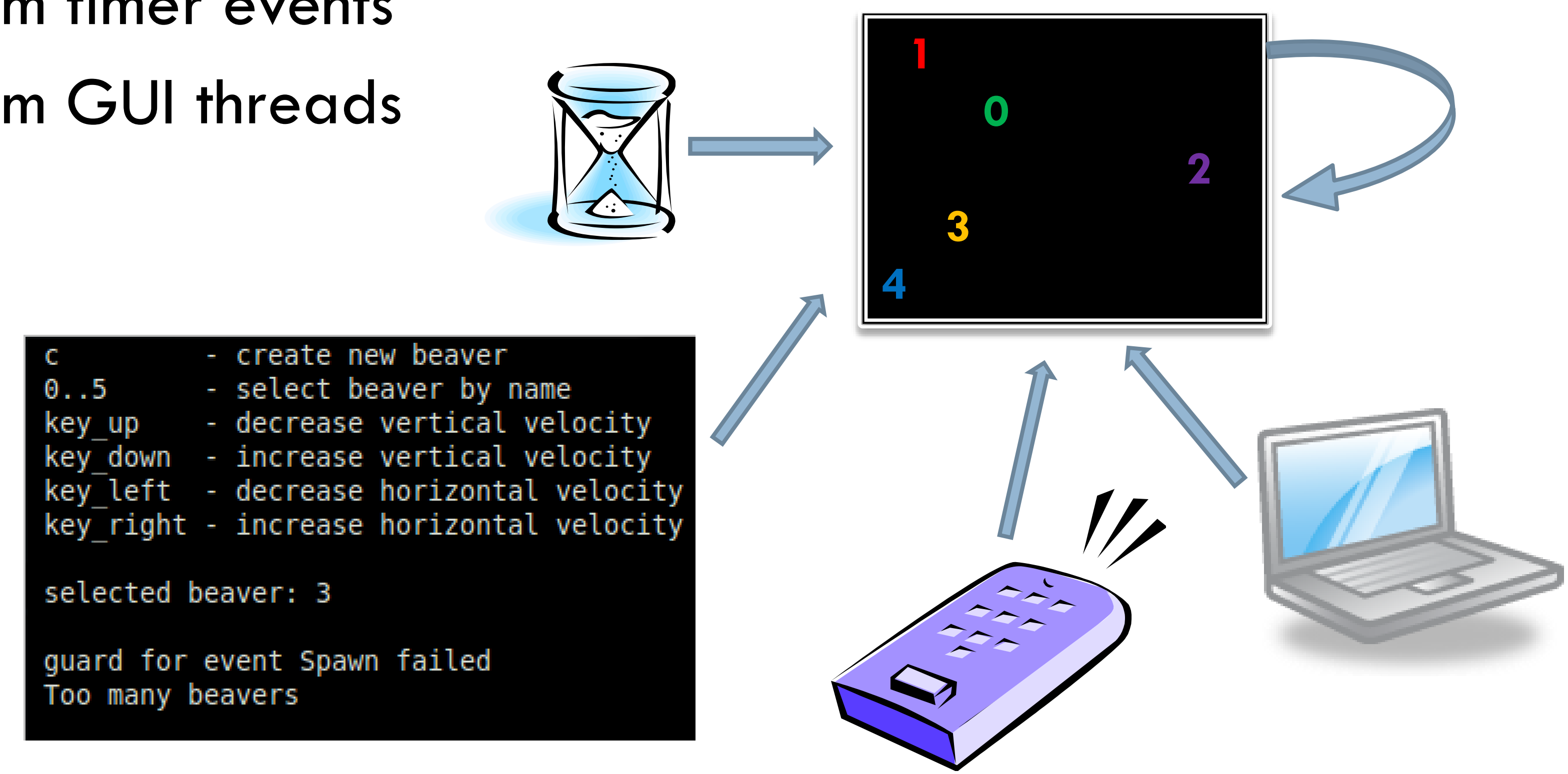
- **Records**
  - simple data structures
  - used to represent the core data model of the system
- **Contexts**
  - encapsulate different processes (nodes)
- **Events**
  - allow robots to dynamically react to their environments
  - triggered by the user, timer, whenever a condition holds, …

Example: BeaverSim

- Implement a beaver simulator:
  (inspired by the ROS turtlesim example)
  - *model*: a beaver has position (x, y) and speed (vx, vy)
  - *constraint*: no more than 5 beavers allowed
  - *every* 1s positions are updated according to speed
  - *whenever* a beavers hits a wall, its speed is reversed
  - one simulator node displays current positions of all beavers
  - arbitrary number of remote controller nodes

Implementation **challenges**

- concurrent access to (shared) beaver data
  - from multiple remote controllers
  - from timer events
  - from GUI threads



Traditional approach to timer events

- fragmented implementation of *whenever* actions
  - *whenever* conditions can turn true at various code points
    - e.g., *(1) when position is auto-updated based on speed and (2) when position is explicitly set by a remote controller*

- fragmented implementation of *constraint* checks
  - have to make sure that invariants hold after every update

REACT: domain-specific **features**

conditional events

```
whenever(condition) {
   [code to execute
    whenever the
    condition is true]
}
```

periodic events

```
every(interval) {
   [code to execute
    every interval ms]
}
```

typed events

```
on EventType {
   [code to execute when
    an event of the
    above type occurs]
}
```

invariants

```
invariant {
   [condition that must
    hold at all times]
}
```

BeaverSim in REACT: **model**

```
MAX_BEAVERS  = 5
MAX_X, MAX_Y = (10, 10)

record Beaver [
  name: str,
  x:    int,
  y:    int,
  vx:   int,
  vy:   int
]

context BeaverSim [
  beavers: listof(Beaver)
] {
  invariant {
    beavers.size() < MAX_BEAVERS
  }
  # ...
}

context RemoteCtrl {
  # ...
}
```

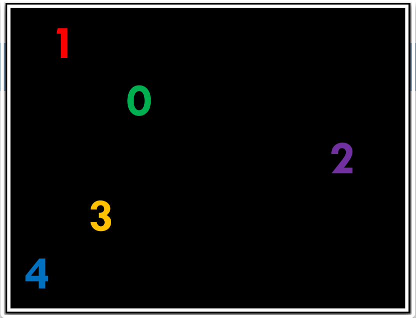
BeaverSim in REACT: **events**

```
event Spawn [
  receiver: BeaverSim,
  name:     str
] {
  guard    { name.length() == 1 }

  handler {
    receiver.beavers += Beaver.new(name: name,
                                   x:  0, y:  0,
                                   vx: 1, vy: 0)
  }
}
```

BeaverSim in REACT: **events**

```
event ChangeSpeed [
  receiver: BeaverSim,
  idx:      int,
  dx:       int,
  dy:       int
] {
  guard   { 0 <= idx < receiver.beavers.size() }

  handler {
    receiver.beavers[idx].vx += dx
    receiver.beavers[idx].vy += dy
  }
}
```

BeaverSim in REACT: **contexts**



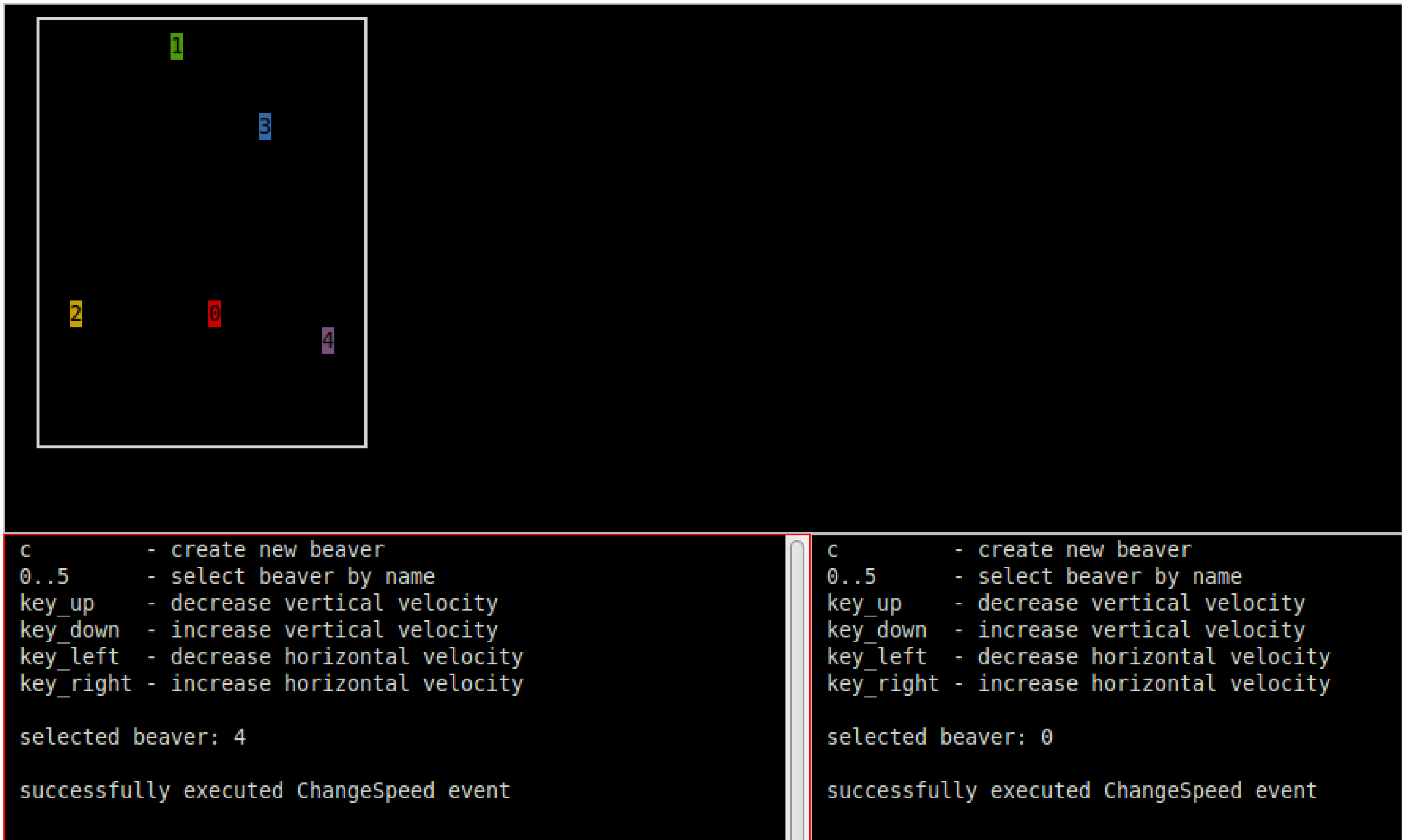

```
context BeaverSim [
  beavers: listof(Beaver)
] {
  on_start      { @gui = MyGui.new; @gui.start() }
  on_exit       { @gui.stop() }

  every(1000) {
    @gui.draw_beavers(beavers)
    for b in beavers { b.x += b.vx; b.y += b.vy }
  }

  whenever(some b in beavers | b.x < 0) {
    b.x = 0; b.vx = -b.vx
  }
}
```

BeaverSim in REACT: **contexts**

```
c          - create new beaver
0..5       - select beaver by name
key_up     - decrease vertical velocity
key_down   - increase vertical velocity
key_left   - decrease horizontal velocity
key_right  - increase horizontal velocity

selected beaver: 3

guard for event Spawn failed
Too many beavers
```

```
context RemoteCtrl {
  on start { @selected = -1 }

  on KEY_0 { @selected = 0 }
  on KEY_4 { @selected = 4 }

  on KEY_c     { trigger Spawn.new(name: 'B') }

  on KEY_UP    { trigger ChangeSpeed.new(idx: @selected
                                         dx: 0, dy: -1)}
  on KEY_DOWN  { trigger ChangeSpeed.new(idx: @selected
                                         dx: 0, dy: 1) }
  on KEY_LEFT  { trigger ChangeSpeed.new(idx: @selected
                                         dx: -1, dy: 0)}
  on KEY_RIGHT { trigger ChangeSpeed.new(idx: @selected
                                         dx: 1, dy: 0) }
}
```

Demo (implemented on top of **ROS**)



Original TurtleSim Spawn event

```
spawn_srv_ = nh_.advertiseService("spawn", &TurtleFrame::spawnCallback, this);
bool TurtleFrame::spawnCallback(turtlesim::Spawn::Request& req, turtlesim::Spawn::Response& res) {
  std::string name = spawnTurtle(req.name, req.x, req.y, req.theta);
  if (name.empty()) { ROS_ERROR("A turtled named [%s] already exists", req.name.c_str());  return false; }
  res.name = name;
  return true;
}
std::string TurtleFrame::spawnTurtle(const std::string& name, float x, float y, float angle) {
  std::string real_name = name;
  if (real_name.empty()) {
    do {
      std::stringstream ss;
      ss << "turtle" << ++id_counter_;
      real_name = ss.str();
    } while (hasTurtle(real_name));
  } else { if (hasTurtle(real_name)) { return ""; } }
   TurtlePtr t(new Turtle(ros::NodeHandle(real_name), turtle_images_[rand() % turtle_images_.size()], QPointF(x, y),
angle));
  turtles_[real_name] = t;
  update();
  ROS_INFO("Spawning turtle [%s] at x=[%f], y=[%f], theta=[%f]", real_name.c_str(), x, y, angle);
  return real_name;
}
```

Original TurtleSim model class

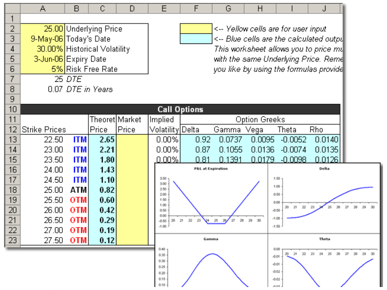
```
class Turtle {
public:
  Turtle(const ros::NodeHandle& nh, const QImage& turtle_image, const QPointF& pos, float orient);
 private:
  void velocityCallback(const geometry_msgs::Twist::ConstPtr& vel);
  bool teleportRelativeCallback(turtlesim::TeleportRelative::Request&, turtlesim::TeleportRelative::Response&);
  bool teleportAbsoluteCallback(turtlesim::TeleportAbsolute::Request&, turtlesim::TeleportAbsolute::Response&);
  ros::Subscriber velocity_sub_;
  ros::Publisher pose_pub_;
  ros::ServiceServer teleport_relative_srv_;
  ros::ServiceServer teleport_absolute_srv_; }

namespace turtlesim {
Turtle::Turtle(const ros::NodeHandle& nh, const QImage& turtle_image, const QPointF& pos, float orient)
: nh_(nh), turtle_image_(turtle_image), pos_(pos), orient_(orient), lin_vel_(0.0), ang_vel_(0.0), pen_on_(true),
pen_(QColor(DEFAULT_PEN_R, DEFAULT_PEN_G, DEFAULT_PEN_B)) {
  velocity_sub_ = nh_.subscribe("cmd_vel", 1, &Turtle::velocityCallback, this);
  pose_pub_ = nh_.advertise<Pose>("pose", 1);
  teleport_relative_srv_ = nh_.advertiseService("teleport_relative", &Turtle::teleportRelativeCallback, this);
  teleport_absolute_srv_ = nh_.advertiseService("teleport_absolute", &Turtle::teleportAbsoluteCallback, this);
}
```

Big Idea

- Generic platform for programming event-driven systems
  - covers a whole class of programs

interactive event-driven apps

spreadsheets →



↓

REACT ⟷ similar to

cms →

- End-user programming of interactive apps
  - examples: social web apps, robots
  - makes simple tasks easy and difficult ones possible

Status

- Prototype for client/server applications
  - implemented in Java
- Prototype for web applications
  - implemented for Ruby on Rails
- Next: look for concrete robot examples
  - robots are event driven, often mission critical
  - adapt our paradigm to programming robots
  - verify functional correctness

Benefits and Future Goals

- Rich programming platform
  - speeds up development process
  - eliminates a whole class of concurrency bugs by construction

- Application in the security domain
  - every field access is managed by the runtime system
  - security policies can be defined independently and automatically enforced at runtime

- Robot programming for end-users

Thank You!

The End

Hello World example

```
context Main {
    /* trigger-event */
    on Main:enter {
        /* action call w/ argument */
        Sys.print! msg:"Hello, world!"
        /* built-in action call */
        Main.exit!
    }
}
```

Outputs: Hello, world!

A more complex example

```
context Headbanger {
        banging = 0
        bangSpeed = 0

        action bangHead! forTime:dur:5000 withEnthusiasm:enth {
                banging = Clock.time + dur
                bangSpeed = enth
        }
        whenever (banging > Clock.time) {
                #spinhead(bangSpeed)
        }
}
context Main {
        on Main:enter {
                Headbanger.enter!
                Headbanger.bangHead! withEnthusiasm:10 forTime:10000
        }
        every (20000) {
                Headbanger.bangHead! withEnthusiasm:20
        }
}
```

Variables

Syntax:

```
(public) (active) name = value
```

where `name` is the variable identifier, `value` is a numerical expression

- `public` modifier allows variable to be visible outside of its own context
- `active` modifier creates an active variable: read-only once defined, and re-evaluate their assigned expression every time they are referenced. They are implemented as in-line function calls

In-depth: 'whenever' vs. 'every' events

Whenever

Syntax:

```
whenever (condition) {
    [code to execute]
}
```

- condition: boolean expression to check
- for direct reactions to changes in the robot's environment

Every

Syntax:

```
every(interval) {
    [code to execute]
}
```

- interval: numerical expression for time interval
- requires some method of retrieving clock ticks

Implementation:

```
last_call = 0
whenever (last_call + interval
    < clock_time) {
    last_call = clock_time
    [code to execute]
}
```

In-depth: 'on' events vs. actions

'on' event

Syntax:

```
on cntxt_name:event_name {
    [code to execute]
}
```

Called explicitly with:

```
trigger cntxt_name:event_name
```

- for reactions to user-defined circumstances
- only execute if context is live

Action

Syntax:

```
action name! <arguments> {
    code
}
```

Argument syntax:

```
ext_name:int_name(:def_val)
```

- Use system of constraints to ensure safety
- Take dynamic arguments

Calling syntax:

```
context_id.action_id!
  <arguments to pass>
```

Embedded C

- Special "C context" construct for creating libraries of C-code interfaceable with REACT, use `_c_context` keyword
- C contexts can contain active variables or actions.

```
_c_context Foo {
    public active c_val = "<C expression>"
    action c_act! withArg:arg:50 "
        [code...]
    "
}
```

- Code copied verbatim from within quotes

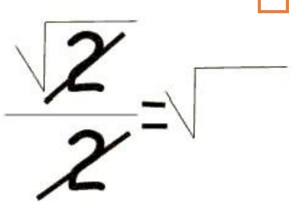
In order to implement APIs for particular robots in REACT, platform-specific code will surely be needed. Embedding native C-code into REACT source can facilitate this.

Technical contributions

- *Expressive power* & *programming efficiency*
- *Programming language* close to the *problem domain*

  - think in terms of simple data structures
  - don't worry about concurrency and distributed architecture
  - declarative programming: say *what* not *how*
- Runtime *environment* + *code generation*

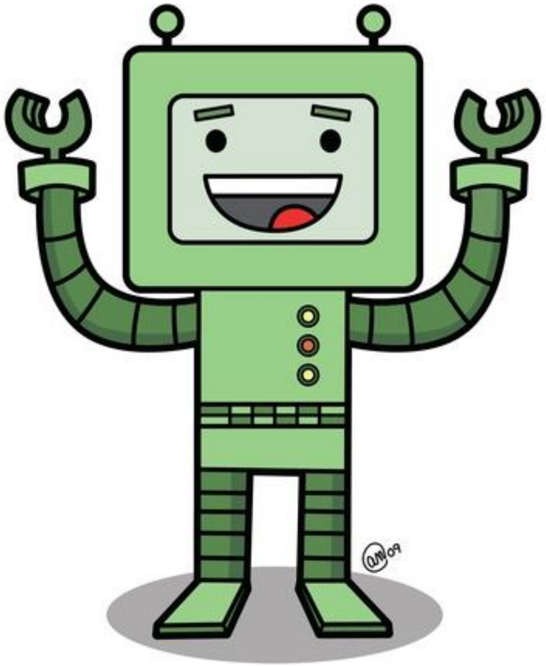
  - no explicit synchronization, queues, message passing
  - no data consistency issues
  - synthesized clients for different platforms
- Amenable to *tools*, *testing*, and formal *analyses*



  - core aspect of the system are kept succinct and formal
  - important for safety/security critical systems

REACT

- Designed to be intuitive and easy to learn
- Powerful expressiveness
- Widespread applications



Proposed Solution

- Model-based, event-driven programming paradigm
  - provides a simple declarative conceptual model
  - expressive power & programming efficiency
  - programming language close to the problem domain
- Runtime environment
  - manages access to single shared global state
  - keeps everyone updated
  - programs free of concurrency bugs by construction
- Rich tool set
  - amenable to formal analyses and automated testing
  - enabled by the succinct and formal event model

REACT summary

- Pros
  - Highly abstract → easy to learn & portable
  - Flexible → can interface with native C code
  - Accessible → robotics programming requires extensive technical knowledge; REACT abstractions eliminate the need for hobbyists to acquire such knowledge.
  - Expressive → programs written faster, robots developed more easily
- Cons
  - Centralized (not designed for distributed systems)
  - Sequential implementation (no concurrent events)
  - No explicit data model
    - data conflated with contexts