Scaling-Up Behavioral Programming: Steps from Basic Principles to Application Architectures

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Overview

- The Behavioral Programming (BP) paradigm
  - Scenario-based programming
- Previous work: BP is incremental & natural
- But does it scale up?

- Attempt to apply BP to a large case-study (a webserver)
- Do BP's desirable traits carry over to large systems?
  - Conclusion: yes, but…
  - With some extensions to BP

Agenda

- Introduction to Behavioral Programming
- Our proposed extensions
- Case-study: a web server

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Behavioral Programming (BP)

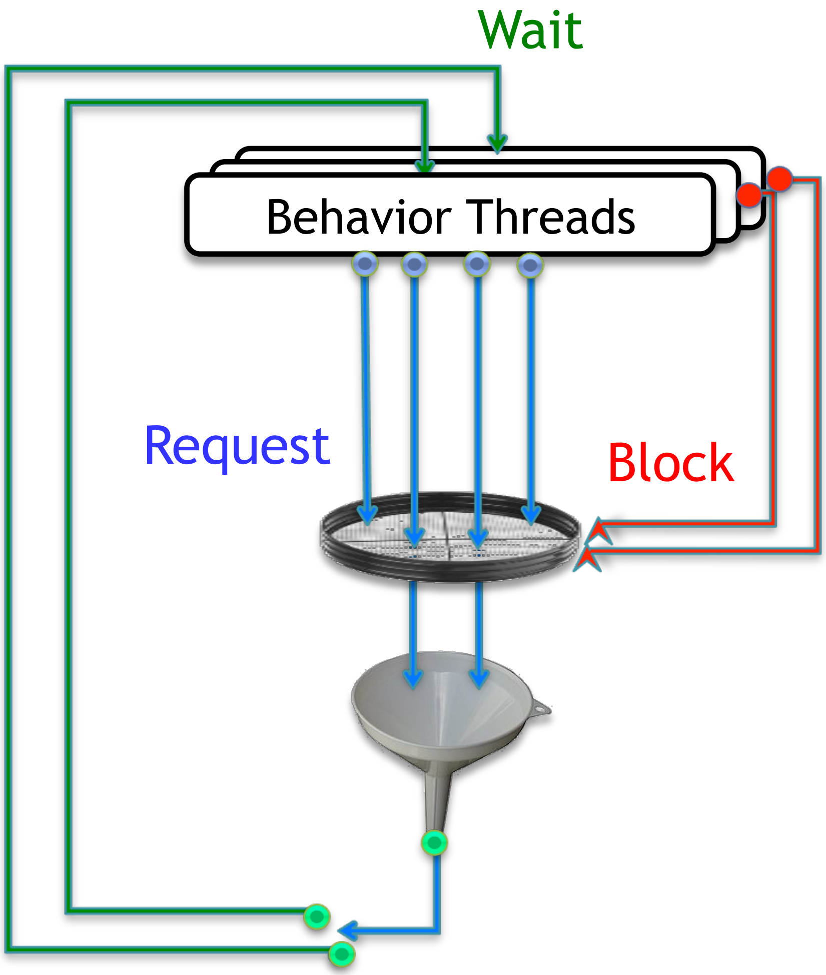
- A scenario-based paradigm for programming reactive systems
- Program by specifying scenarios
  - Desirable scenarios
  - Undesirable scenarios
- All scenarios are consulted at runtime
  - Producing cohesive system behavior

Harel et al, "Behavioral Programming", ***CACM, 2012***

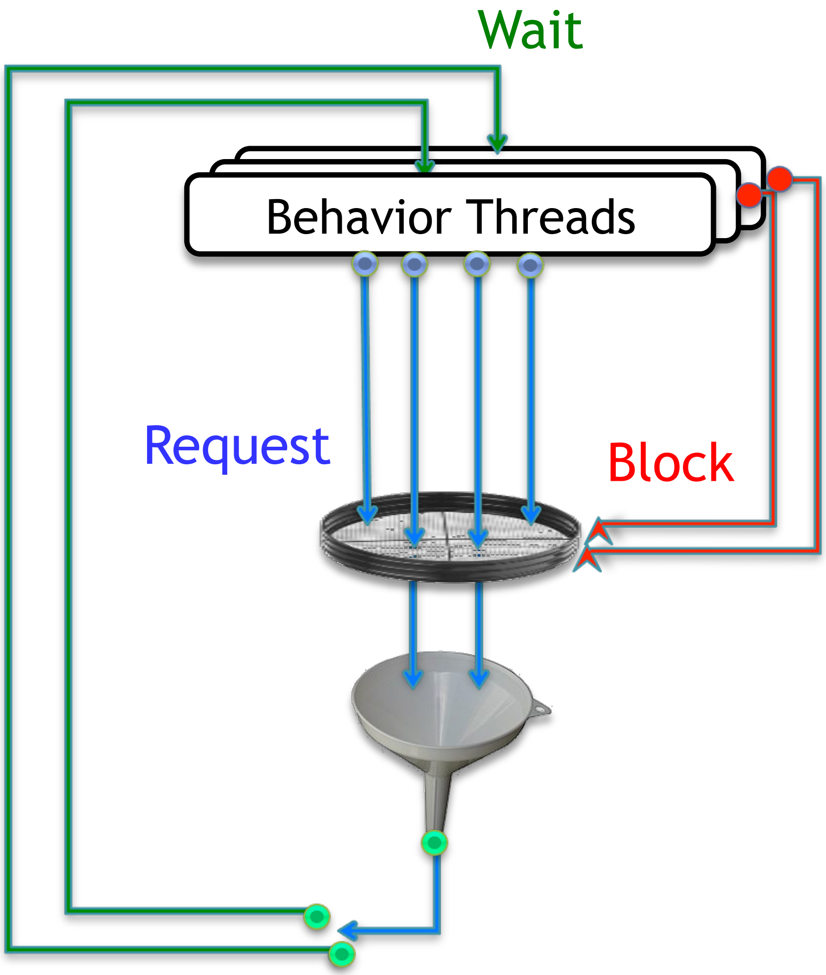
Behavioral Programming (cnt'd)

- A program has events and threads
- At synchronization points threads pause and declare
  1. Requested events
  2. Waited-for events
  3. Blocked events
- Event selection at synchronization points:
  1. Trigger an event requested by some thread and blocked by none
  2. Inform threads that requested/wait-for the event

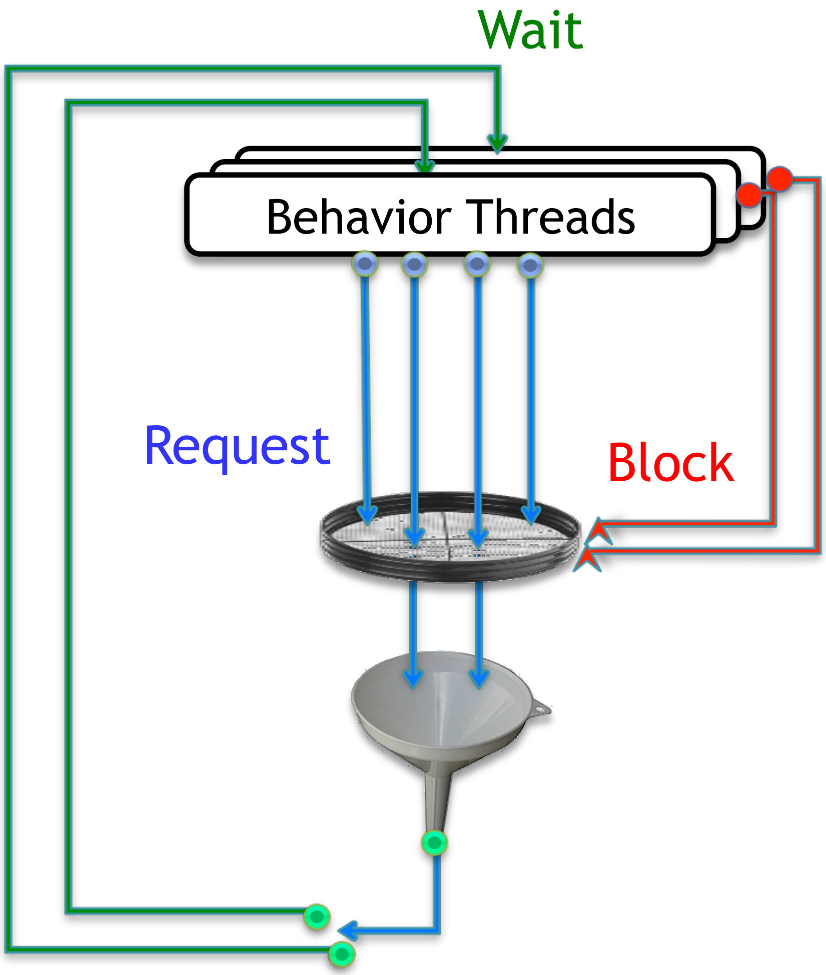
The Execution Cycle



The Execution Cycle



The Execution Cycle



Toy Example

```
AddHotFiveTimes() {
   for i=1 to 5 {
      bSync(request=addHot, wait-for=∅, block=∅);
   }
}
```

```
AddColdFiveTimes() {
   for i=1 to 5 {
       bSync(request=addCold, wait-for=∅, block=∅);
   }
}
```

```
Interleave() {
   forever {
      bSync(request=∅, wait-for=addHot, block=addCold);
      bSync(request=∅, wait-for=addCold, block=addHot);
   }
}
```

```
addHot
   addCold
addHot
   addCold
addHot
   addCold
addHot
   addCold
addHot
   addCold
```

Motivation for BP

- Incremental, non-intrusive development
  - New requirement? Add a thread
  - Program repair
- Threads aligned with the specification
- Natural / easy to learn
- Fosters abstract programming

BP and the Actor Model

- Similarities:
  - Actors / Behavior Threads: narrow view of the system
  - Event passing between threads
- Differences:
  - Synchronization is global
  - Undesired behaviors/the blocking idiom
- We regard Actors and BP as complementary

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Time in BP

- Traditional BP assumed zero-time actions
  - Threads re-synchronize immediately
- Threads with multiple time scales?
- Partial solutions exist (Harel et al, *AGERE!* 2011)
- But, no way to *reason* about time

Example: Railway Crossing

- Upon *trainComing*, lower the gate
- The gate must remain down for 30 seconds

```
Thread LowerGate
  while ( true )
      bSync(request=∅, wait-for=trainComing, block=∅)
      bSync(request=lowerGate, wait-for=∅, block=∅)
```

```
Thread PreventRaise
  while ( true )
      bSync(request=∅, wait-for=lowerGate, block=∅)
      bSync(request=∅, wait-for=∅, block=raiseGate)
```

Extension: A Timeout Idiom

- Extend synchronization calls with a timeout parameter

  bSync(request, wait-for, block, timeout)
- Threads synchronize, and an enabled event is triggered
- No enabled events? Wait for nearest timeout value
- Wake up the thread that timed-out
  - That thread may change the requested/blocked events

```
Thread PreventRaise
  while ( true )
      bSync(∅, lowerGate, ∅, ∞)
      bSync(∅, ∅, raiseGate, 30)
```

Strategies

- Often, multiple events requested and not blocked
  - Which is triggered?
- Traditional solutions:
  - Arbitrary
  - Event / thread priorities
  - Round robin
- Our extension: selection strategy a part of the program
  - Tailor event selection to programmer's needs

Dynamic Thread Creation

- Previously, threads exist throughout the run
- Difficult to handle requirements that change throughout the run
  - E.g., user action creates a thread
- Our extension: dynamic thread creation
  - Threads spawn other threads, in response to events

Parameterized Events

- Previous programs dealt finitely many events
- Explicitly name all possible events…
- Our extension: allow events with parameters

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The Project

- Large scope: a TCP stack and a HTTP stack
  - Together, they form a webserver
- Various programming tasks: timeouts, string manipulation, file access, checksums, multiple inputs, mandatory and forbidden behavior, etc.

- Goal: find out whether this is feasible using BP
  - Answer: yes, with the aforementioned extensions
- Sub-goals:
  - Program incrementally
  - Align threads with the specifications

The Need for the Extensions

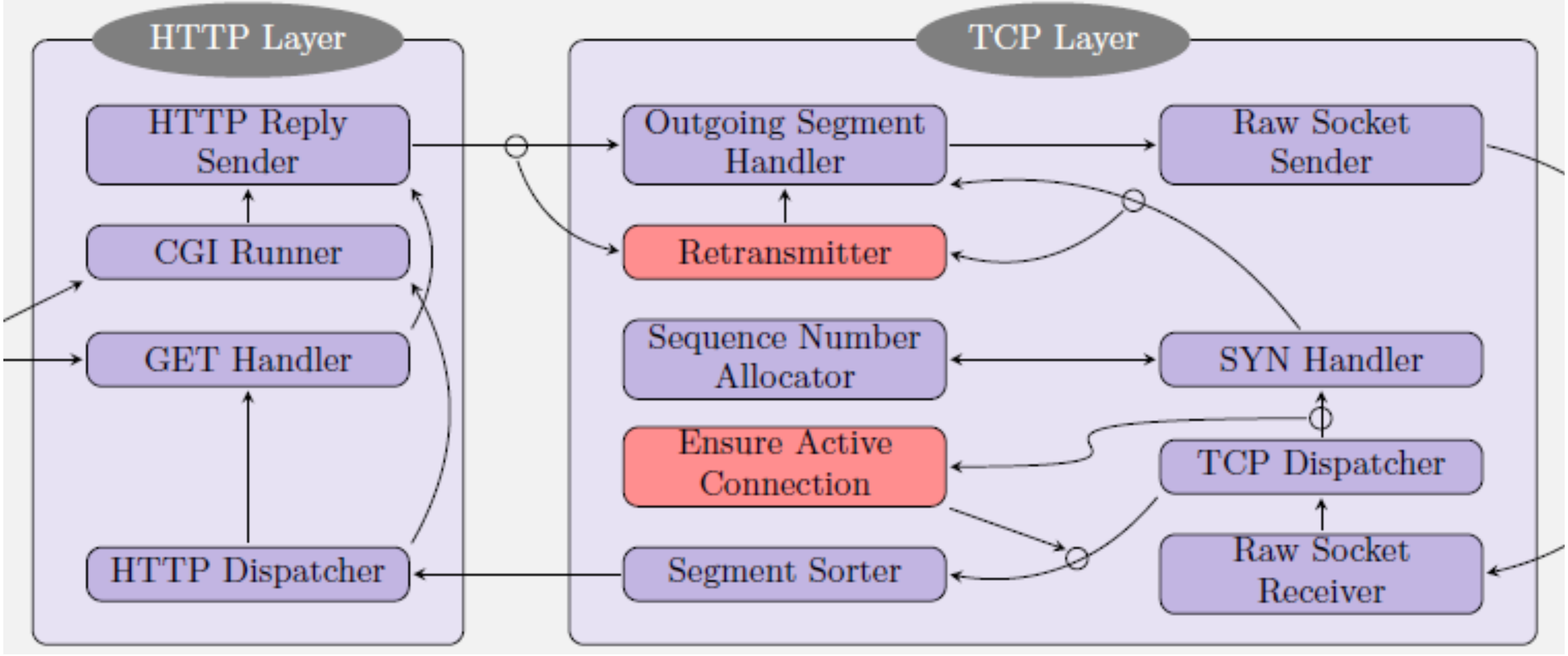
- Timeouts:
  - Every TCP segment needs to be acknowledged
  - Otherwise, resend it

```
Thread ResendSegment
   do {
      bSync(sendSegment, ∅, ∅, ∞)
      bSync(∅, ack, ∅, 2)
   } while ( timeoutInLastSync() )
```

The Need for the Extensions

- Spawn Threads: new thread per connection
- Strategies: answer urgent segments first
- Parameterized events: carry a segment’s payload

The Implementation's Layout



Conclusions & Future Work

- We've developed a large behavioral application
- In the process, extended BP with:
  - Timeouts
  - Dynamic Thread Creation
  - Strategies
  - Parameterized events

- In the future: extend our case study
  - May reveal additional idioms worth adding to BP
- Extend program analysis tools (model-checking, repair, etc) to the new variant of BP

Thank You!

Questions