RE^{X}: A Development Platform and Online Learning Approach for Runtime emergent software systems

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MOTIVATION

- Modern software remains **highly complex** to design, implement, maintain & configure, particularly for dynamic environments
  - this causes high development costs and under-performing code

- The state of the art in solving this is **self-adaptive systems**, which exhibit some awareness of *self* and of *environment*
  - However, these approaches relate only to the configuration element of systems development, and are also very manual in their definition, by:
    - Designing the base system as a non-adaptive one
    - Deciding which points of that system should be adaptable
    - Writing rules to determine how and when adaptation happens

CONCEPT OVERVIEW

- We propose a paradigm of **continuous self-assembly**, in which the *initial construction* of software and its *later adaptation* are one continuous machine-driven process

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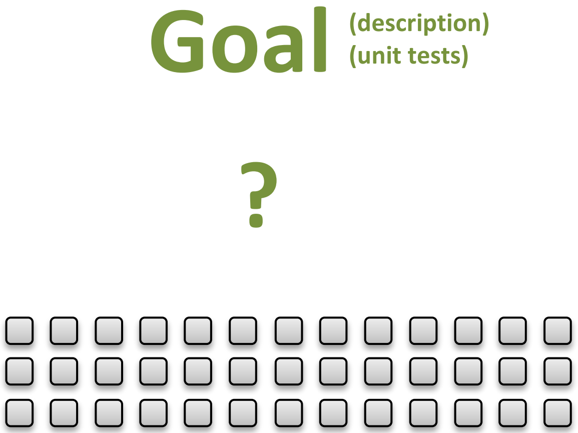

Start with a goal and a pool of behavior fragments

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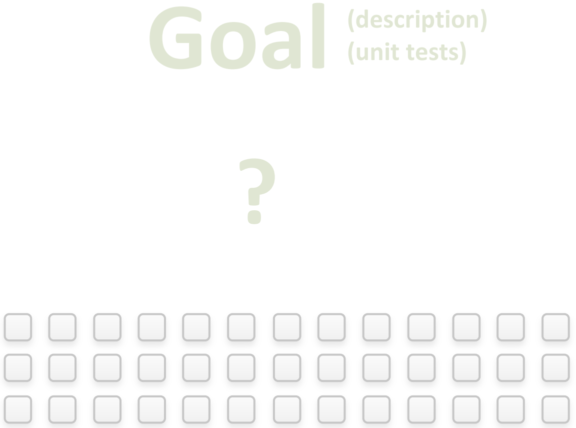

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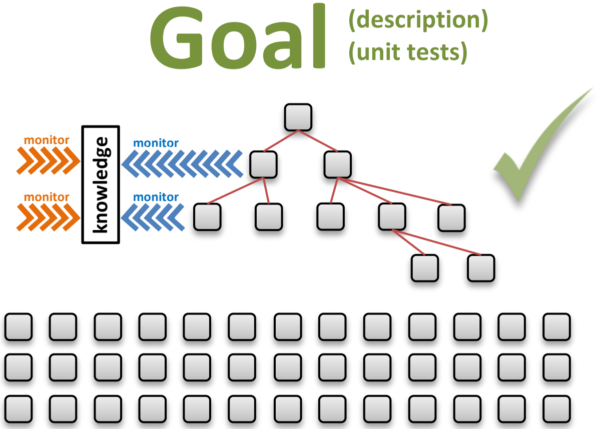

*Form a working system for the goal, deploy in production environment and monitor **performance** and **environment***

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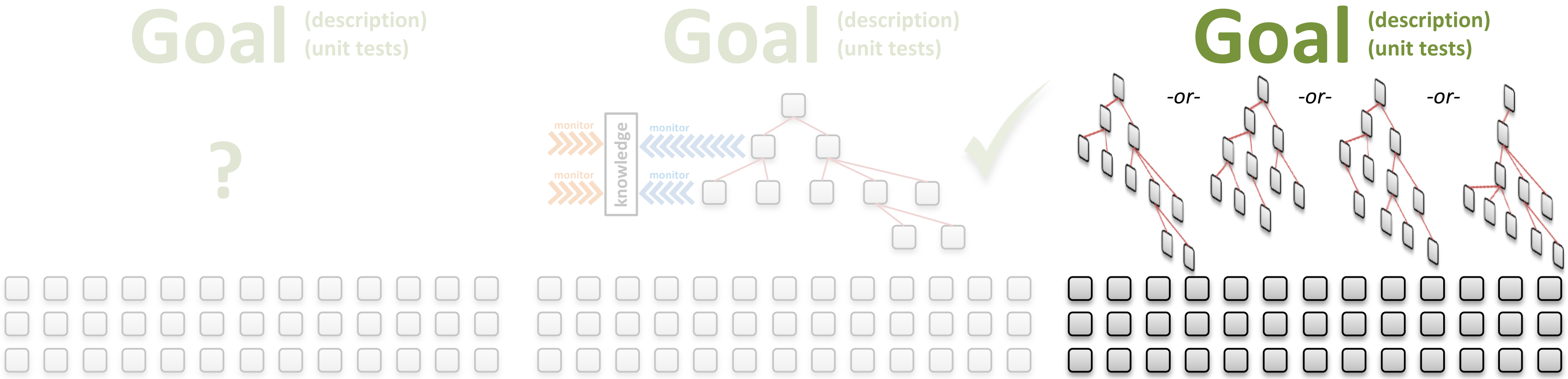


Start with a goal and a pool of behavior fragments

*Form a working system for the goal, deploy in production environment and monitor **performance** and **environment***

*Learn & find (or create) variants to better **shape the system to its environment***

CONTRIBUTIONS

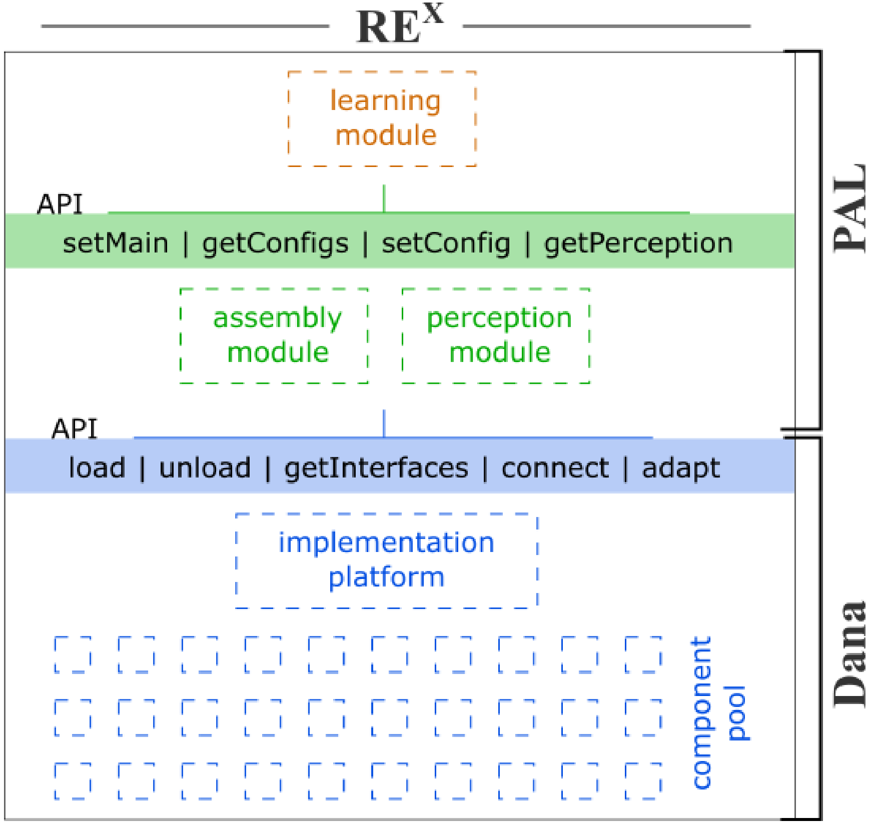
- **Implementation platform (*Dana*):** A programming language with which to create small software building blocks that can be assembled into emergent systems, with near-zero-cost runtime adaptation for online exploration.

- **Perception, assembly and learning framework (*PAL*):** A framework built with Dana to discover & assemble emergent software, perceive its effectiveness and deployment conditions, and feed perception data to online learning.

- **Online learning approach:** An application of statistical linear bandits, using Thompson sampling, to help solve the search space explosion inherent in our approach, by sharing beliefs about components across possible configurations.

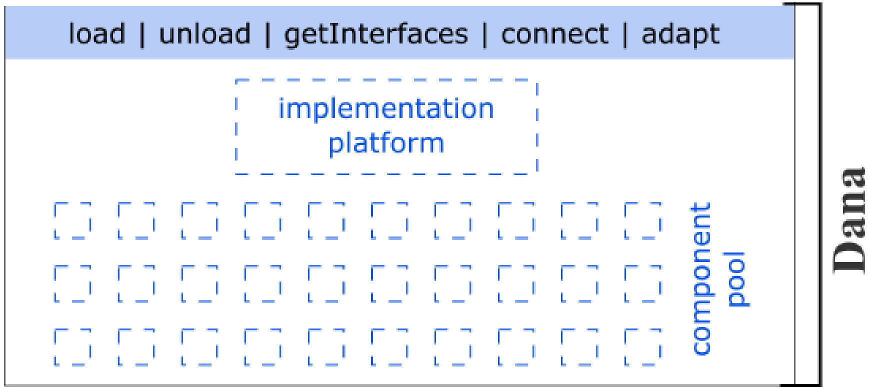
Example system: an emergent, self-assembling web server

APPROACH IN DETAIL



APPROACH IN DETAIL – IMPLEMENTATION PLATFORM

- Uses a **component-based development** paradigm, but:
  (i) infused in a generalised systems programming language;
  (ii) supporting very fast, fine-grained runtime adaptation; and
  (iii) removing the need for wiring diagrams / configurations



Approach in Detail – Implementation platform

- Uses a **component-based development** paradigm

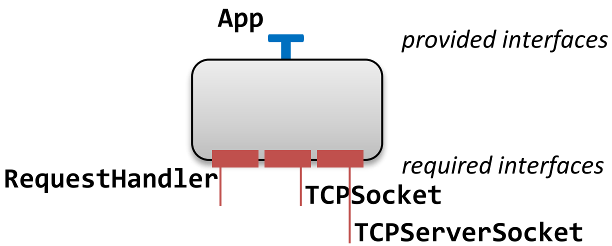
```
interface RequestHandler {
 void handleRequest(TCPSocket s)
}
```

```
component provides App requires net.TCPSocket,
                          net.TCPServerSocket,
                    request.RequestHandler rh {

 int App:main(AppParam params[]) {
  TCPServerSocket host = new TCPServerSocket()
  host.bind(TCPServerSocket.ANY_ADDRESS, 8080)

  while (true) {
   TCPSocket client = new TCPSocket()
   if (client.accept(host))
    rh.handleRequest(client)
  }

  return 0
 }
}
```



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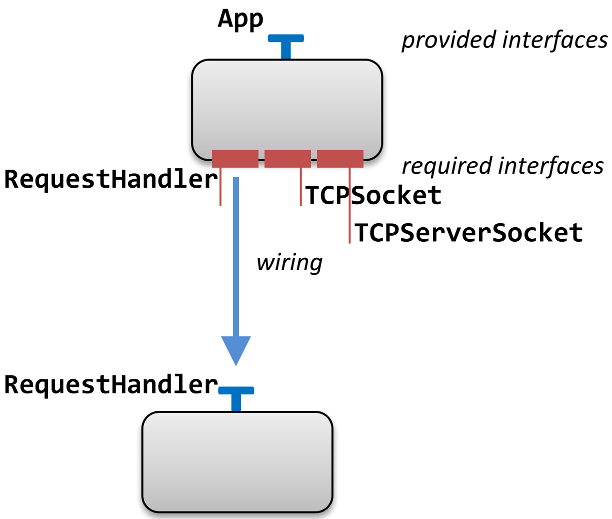

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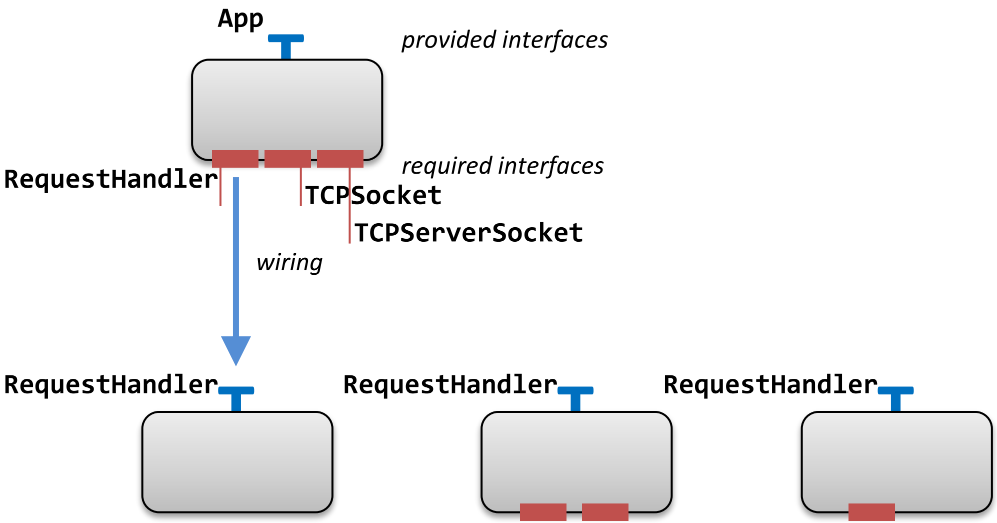
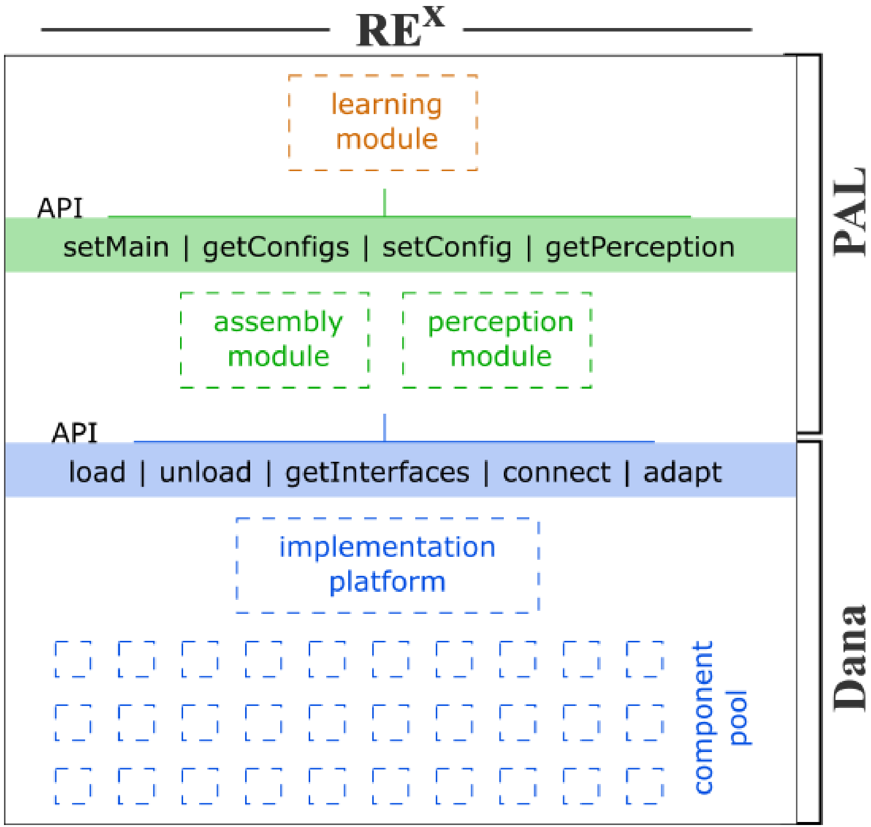


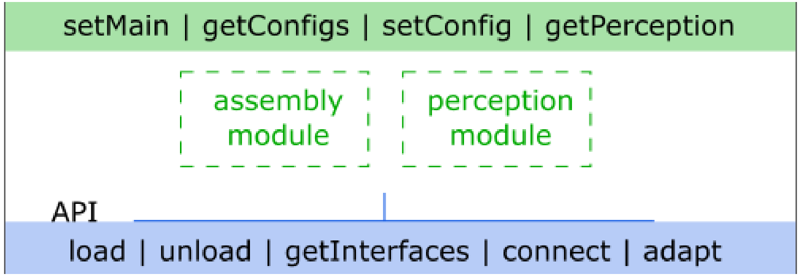
implementation variants: components that provide the same interface but implement it in different ways, yielding different behaviour or performance

APPROACH IN DETAIL



APPROACH IN DETAIL – PERCEPTION, ASSEMBLY AND LEARNING

- A way to **abstract entire software systems** for machine learning into: reward; environment; actions



setMain | getConfigs | setConfig | getPerception

assembly module

perception module

API

load | unload | getInterfaces | connect | adapt

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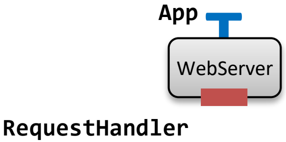

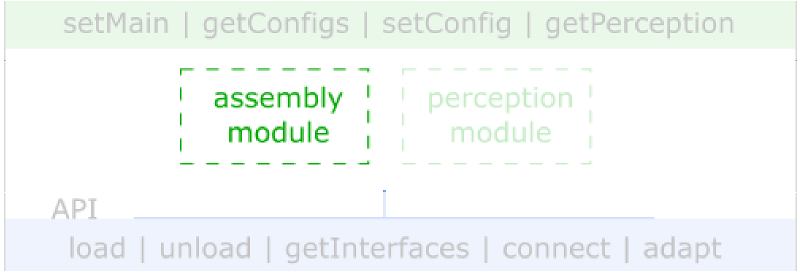
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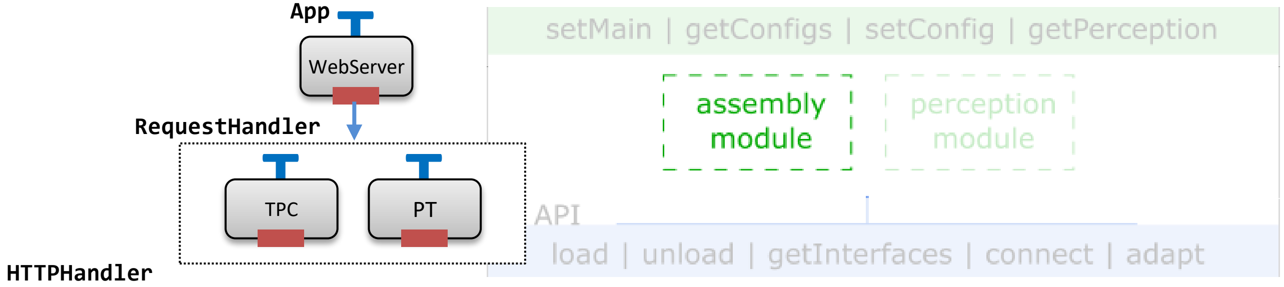
App
WebServer
RequestHandler
TPC
PT
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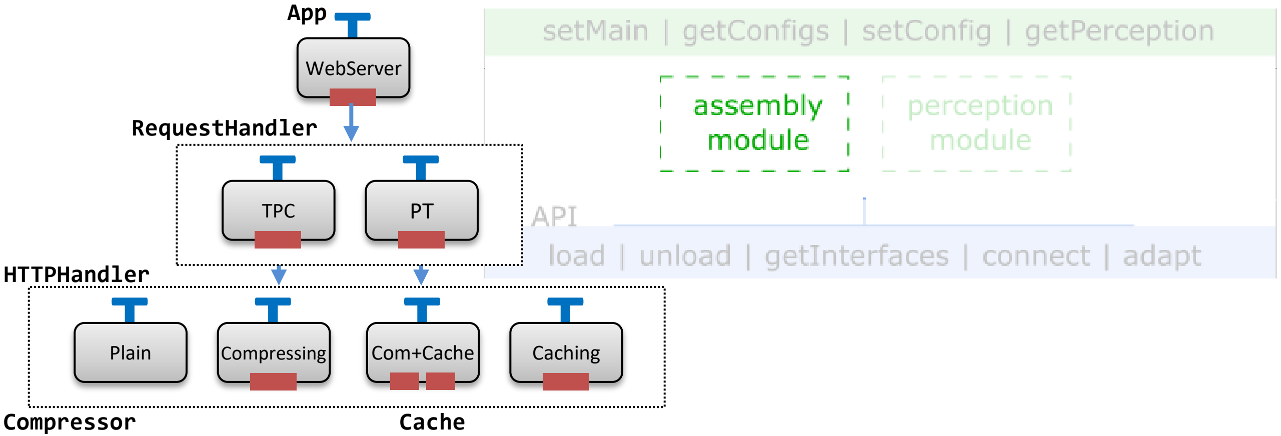

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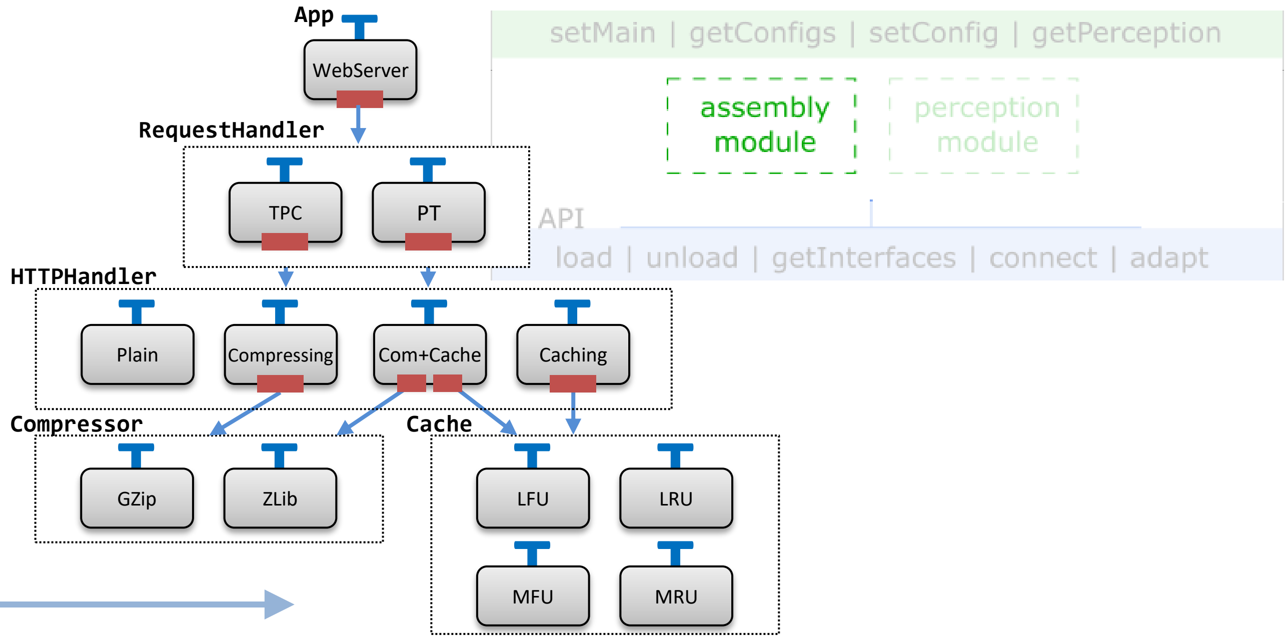

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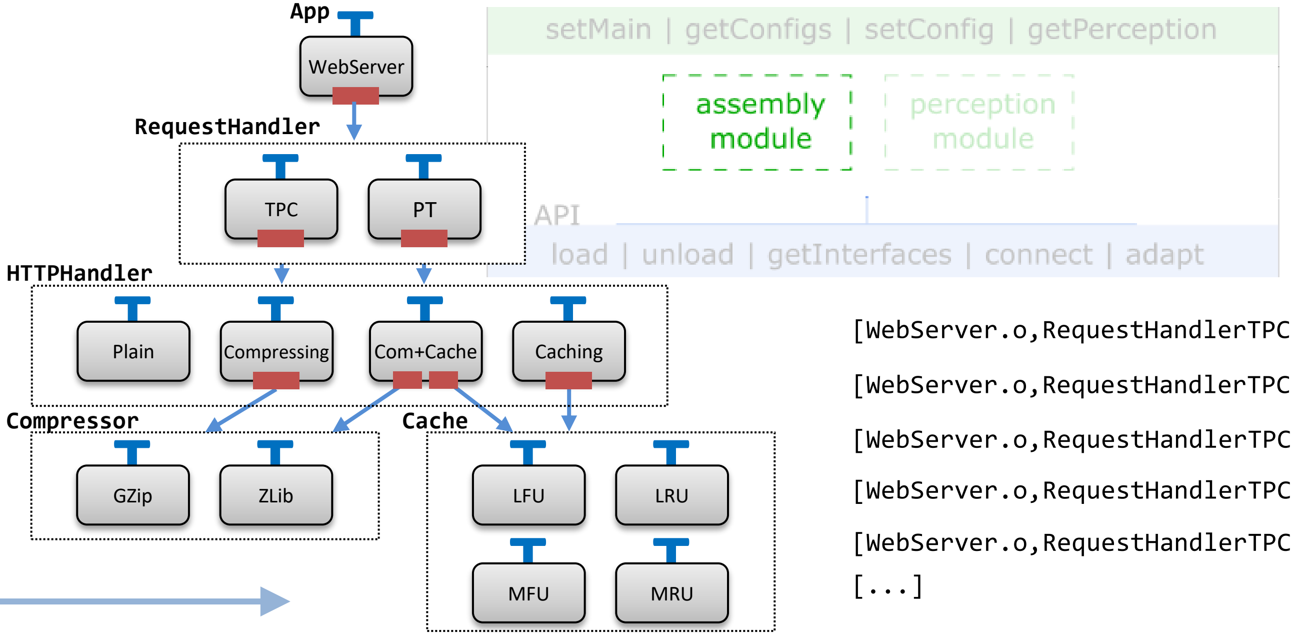

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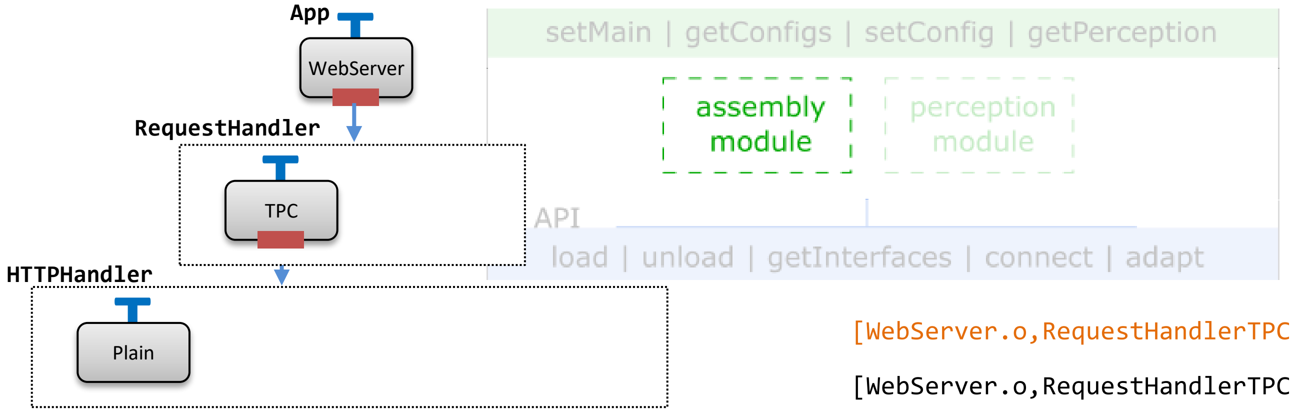
App
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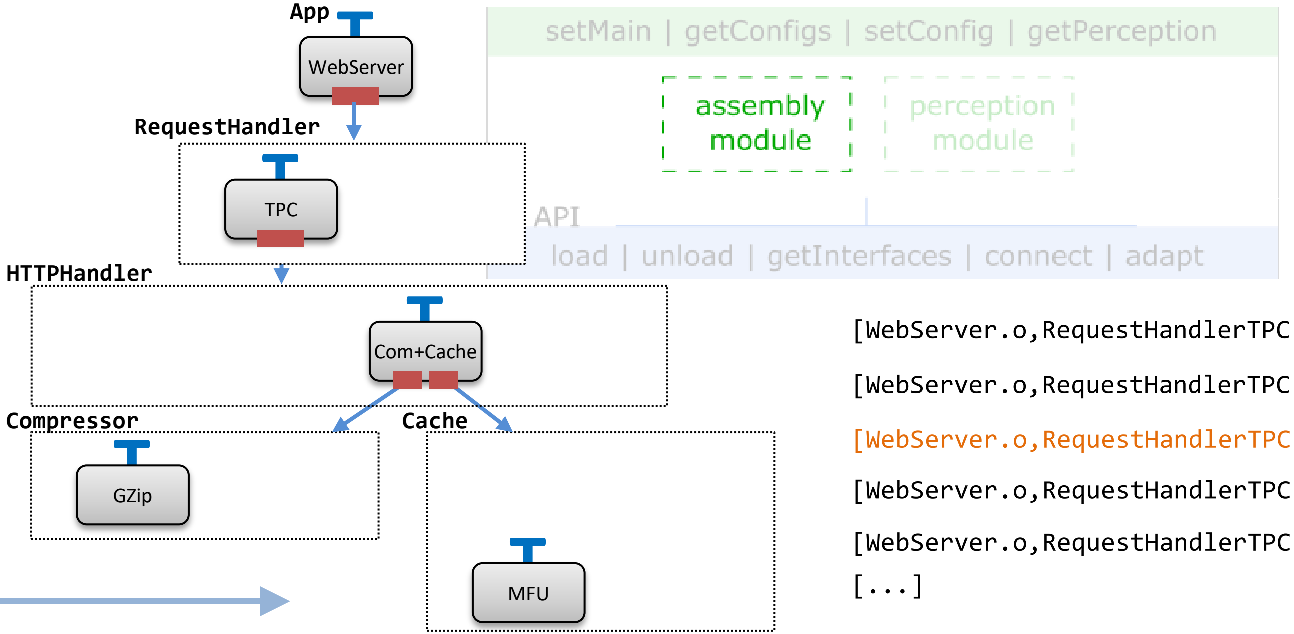

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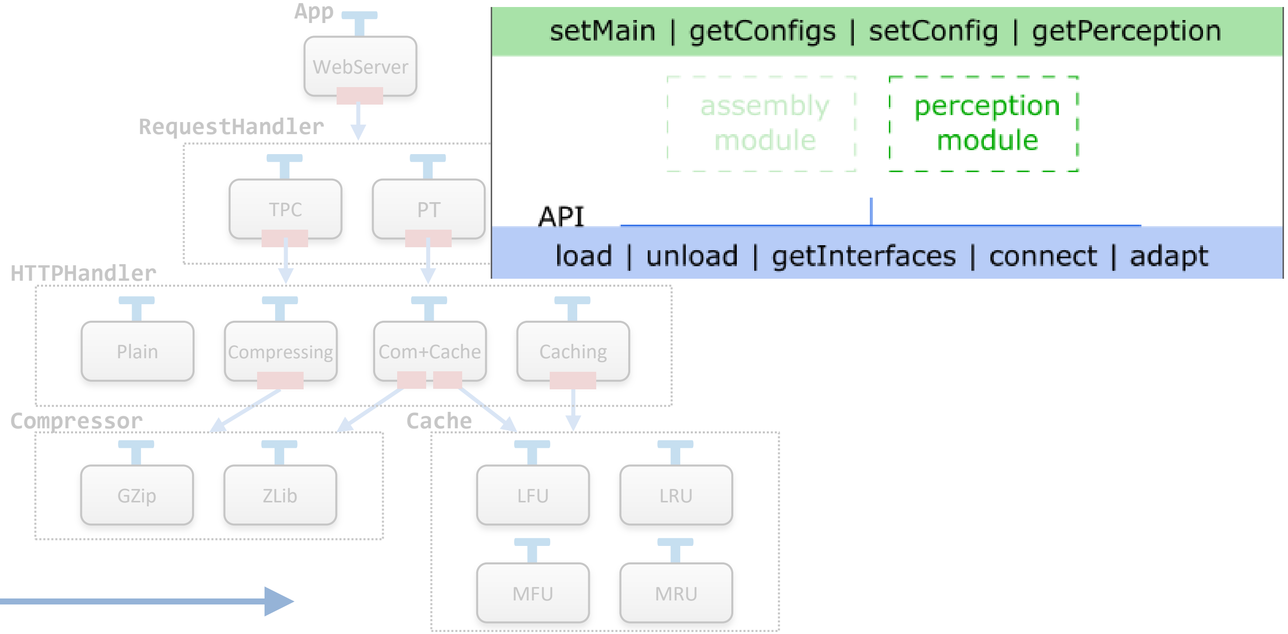

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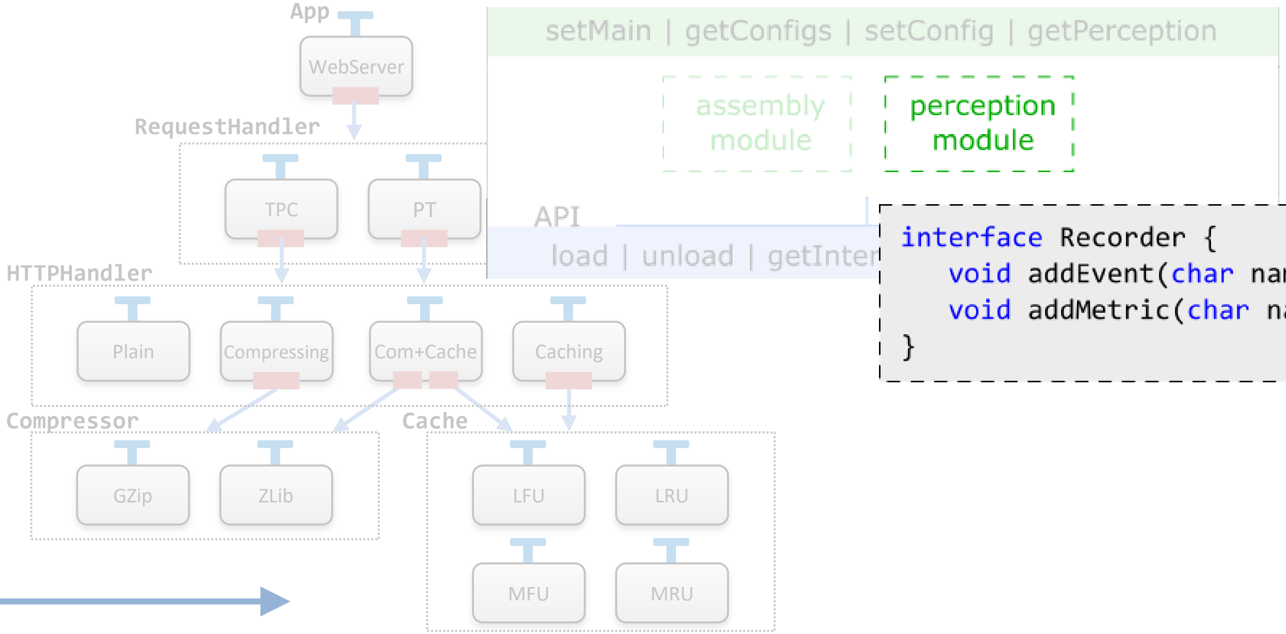

```
interface Recorder {
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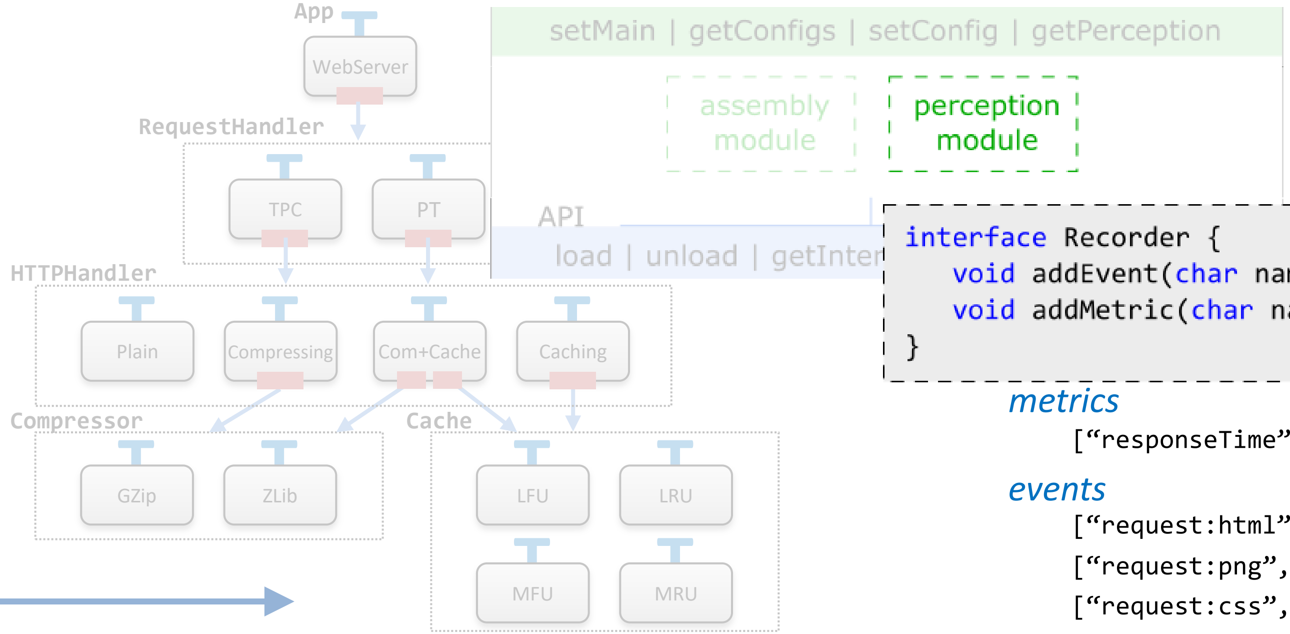

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```

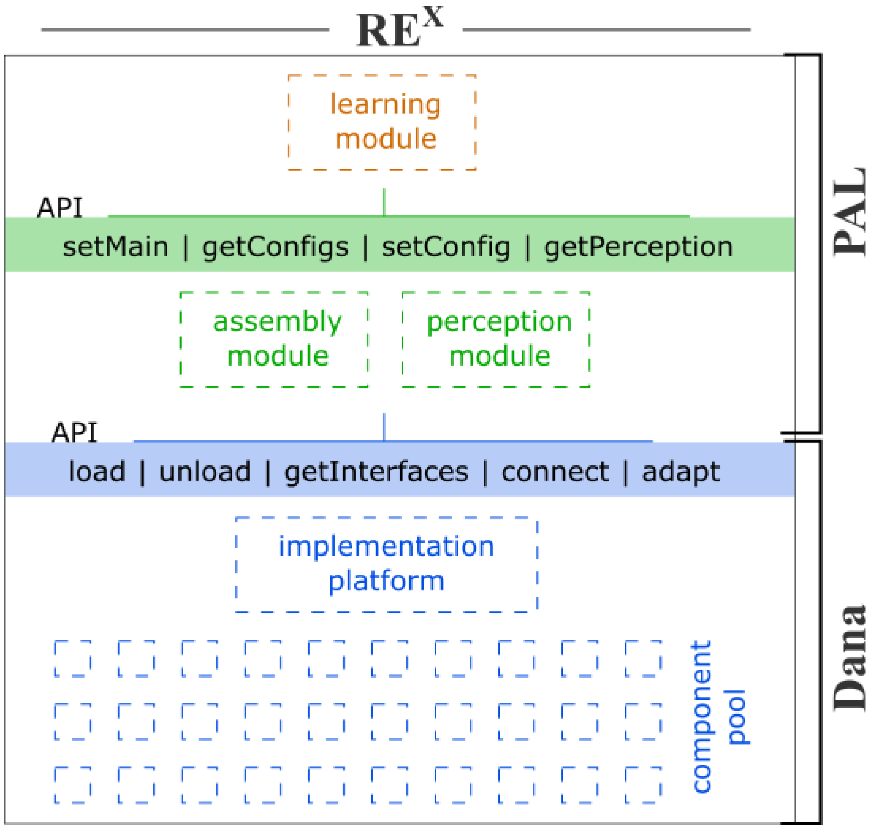
metrics

```
["responseTime", 49, 32, true]
```

events

```
["request:html", 5392, 14]
["request:png", 16702, 12]
["request:css", 2420, 6]
```

APPROACH IN DETAIL



APPROACH IN DETAIL – LEARNING MODULE

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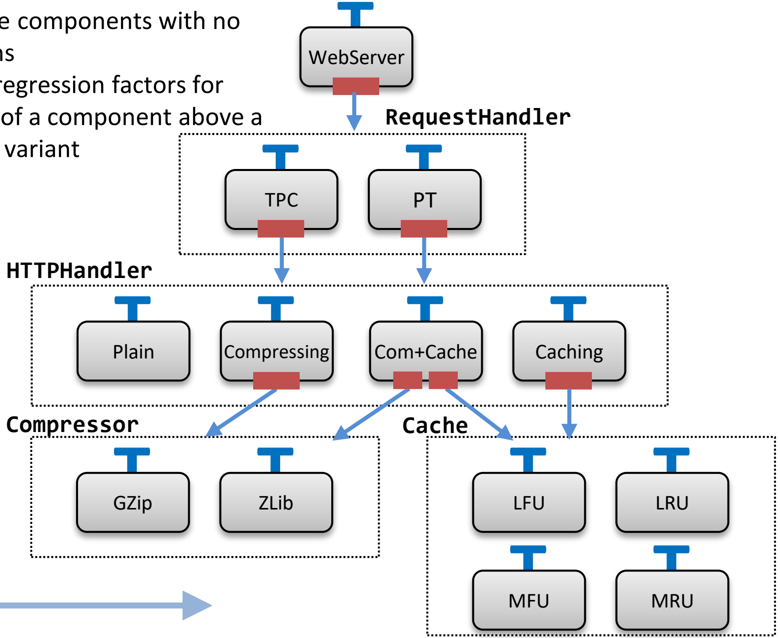

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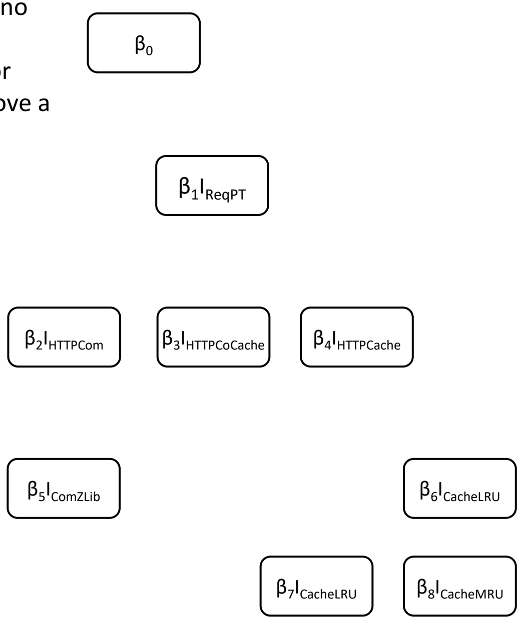

β_0

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TPC.Plain	**PT.Plain**	**TPC.Com.GZip**	**TPC.Com.ZLib**	**…**
β_0 1	β_0 1	β_0 1	β_0 1	…
β_1 0	β_1 1	β_1 0	β_1 0	…
β_2 0	β_2 0	β_2 1	β_2 1	…
β_3 0	β_3 0	β_3 0	β_3 0	…
β_4 0	β_4 0	β_4 0	β_4 0	…
β_5 0	β_5 0	β_5 0	β_5 1	…
β_6 0	β_6 0	β_6 0	β_6 0	…
β_7 0	β_7 0	β_7 0	β_7 0	…
β_8 0	β_8 0	β_8 0	β_8 0	…

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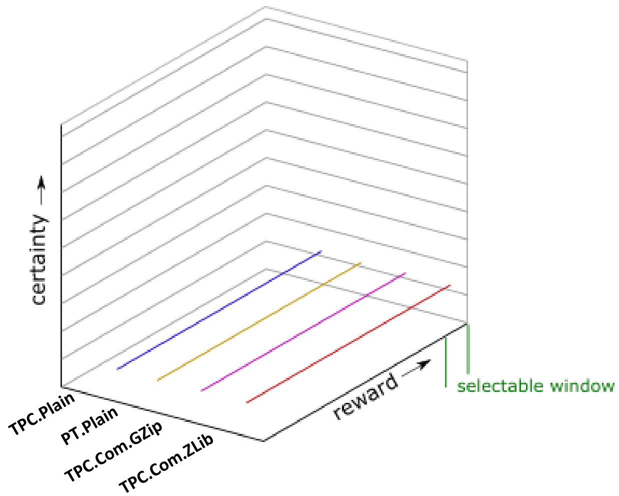

every *n* seconds, select a composition that we either (1) know little about; or (2) know performs well

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β_1 0	β_1 1	β_1 0	β_1 0	...
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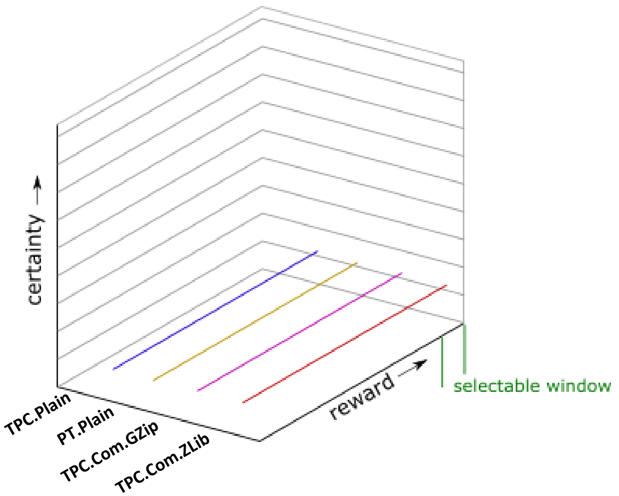
β_7 0	β_7 0	β_7 0	β_7 0	...
β_8 0	β_8 0	β_8 0	β_8 0	...

select



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β_4 0	β_4 0	β_4 0	β_4 0	...
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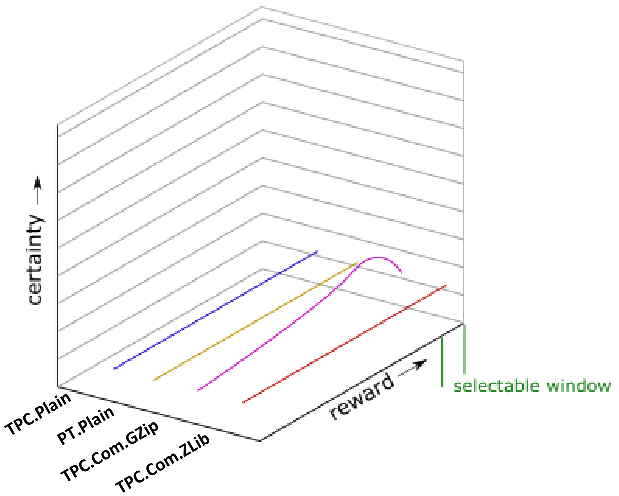
β_6 0	β_6 0	β_6 0	β_6 0	...
β_7 0	β_7 0	β_7 0	β_7 0	...
β_8 0	β_8 0	β_8 0	β_8 0	...

select



observe reward, update estimates

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β_3 0	β_3 0	β_3 0	β_3 0	…
β_4 0	β_4 0	β_4 0	β_4 0	…
β_5 0	β_5 0	β_5 0	β_5 1	…
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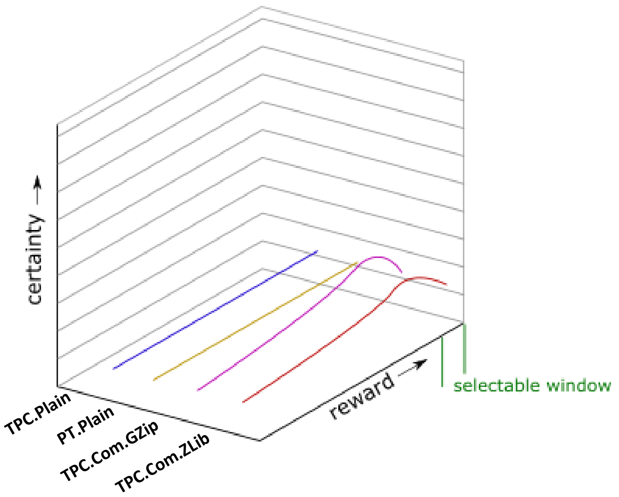
select



share estimates across configurations

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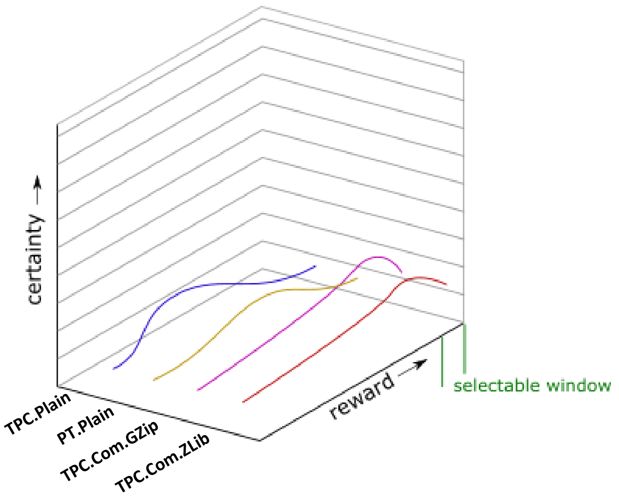
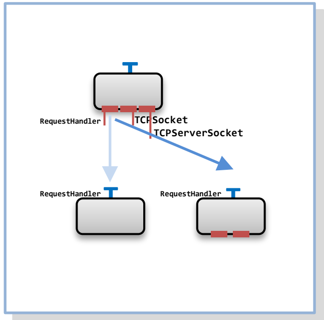
β_2 0	β_2 0	β_2 1	β_2 1	...
β_3 0	β_3 0	β_3 0	β_3 0	...
β_4 0	β_4 0	β_4 0	β_4 0	...
β_5 0	β_5 0	β_5 0	β_5 1	...
β_6 0	β_6 0	β_6 0	β_6 0	...
β_7 0	β_7 0	β_7 0	β_7 0	...
β_8 0	β_8 0	β_8 0	β_8 0	...

select

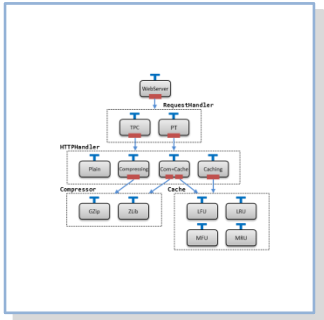


continue learning…

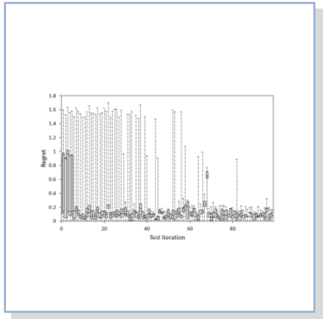
EVALUATION



Adaptation speed



Performance ground truth



Learning characteristics

Evaluation – learning characteristics

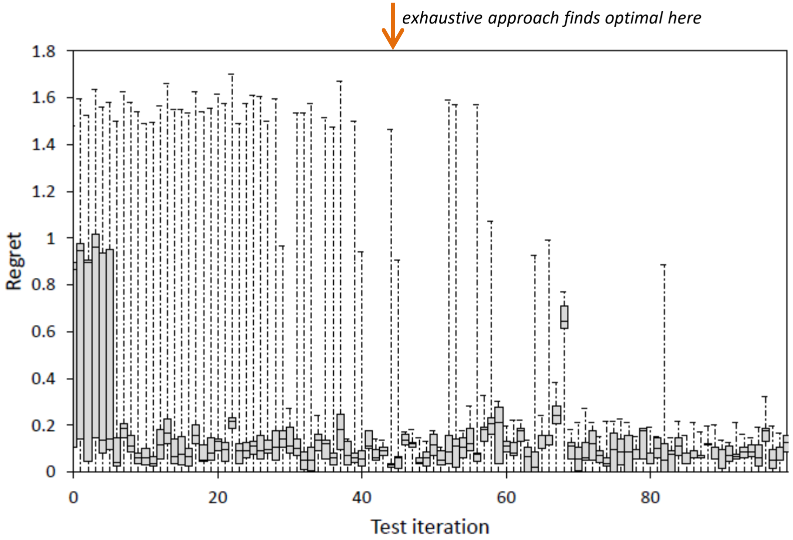
- Using our web server as an example, we evaluate how optimal systems emerge over time in our approach

- We use a set of different workloads (client request patterns), including synthetic and real-world traces

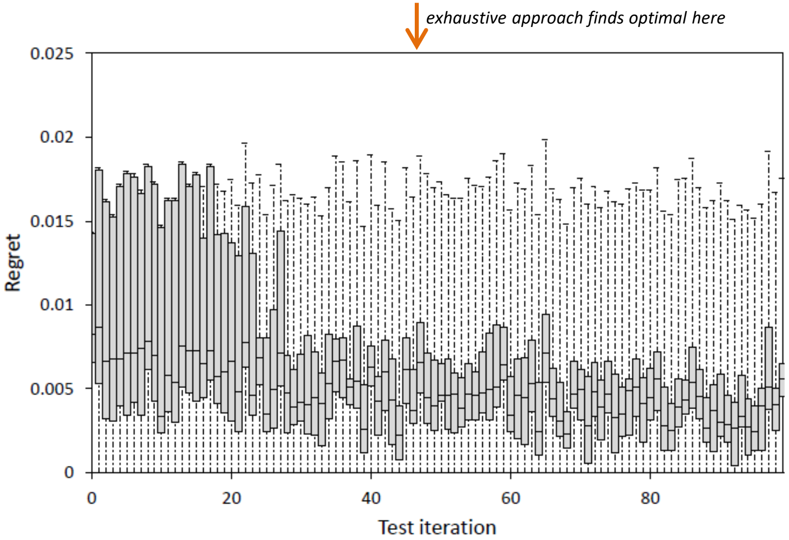
- The only data available for learning is **(i)** the configuration set; and **(ii)** the metrics and events that the system emits (in this case, response times and request types/volumes)

EVALUATION – LEARNING CHARACTERISTICS

Key result: convergence on optimal solution happens much faster than exhaustive search



Workload: small text files

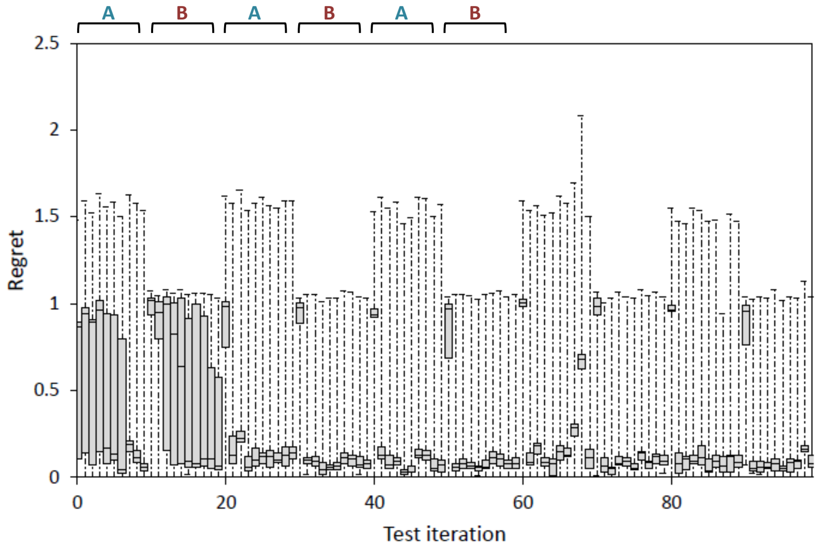


Workload: large image files

Distance from optimal solution over time, averaged across 1,000 runs

Evaluation – learning characteristics

Key result: once learned, workload changes are rapidly detected and adjusted to

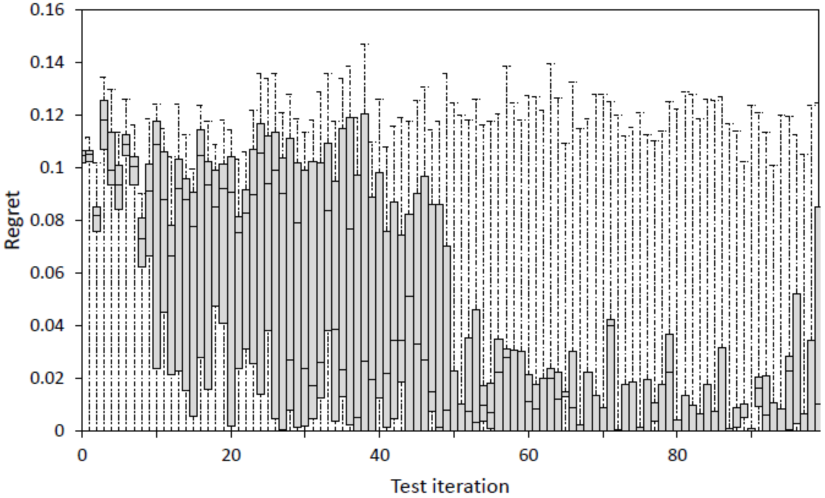


Workload: cycling between two different request patterns every 100 seconds

Distance from optimal solution over time, averaged across 1,000 runs

EVALUATION – LEARNING CHARACTERISTICS

Key result: convergence occurs in a highly varying real-world workload trace



Workload: real-world workload taken from a publicly available NASA web server trace

Distance from optimal solution over time, averaged across 1,000 runs

EVALUATION – OTHER INSIGHTS

- More broadly, *unexpected* optimal designs that emerged due to machine learning were some of the most interesting results

- This highlighted cases in which our assumptions were wrong about how a given composition would behave, or examples of programmer error / poor design choices

Summary

- Presented the idea of *emergent software systems* as a new solution to system complexity and deployment dynamics

- We use a paradigm of continuous self-assembly, finding optimal systems via automated composition from small building blocks

- Future work: studying more applications (other server types, AI, robotics); automated generation of variants; automated environment classification; distributed emergent systems (e.g. entire datacentre software landscapes)

- download our code at http://www.projectdana.com -

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