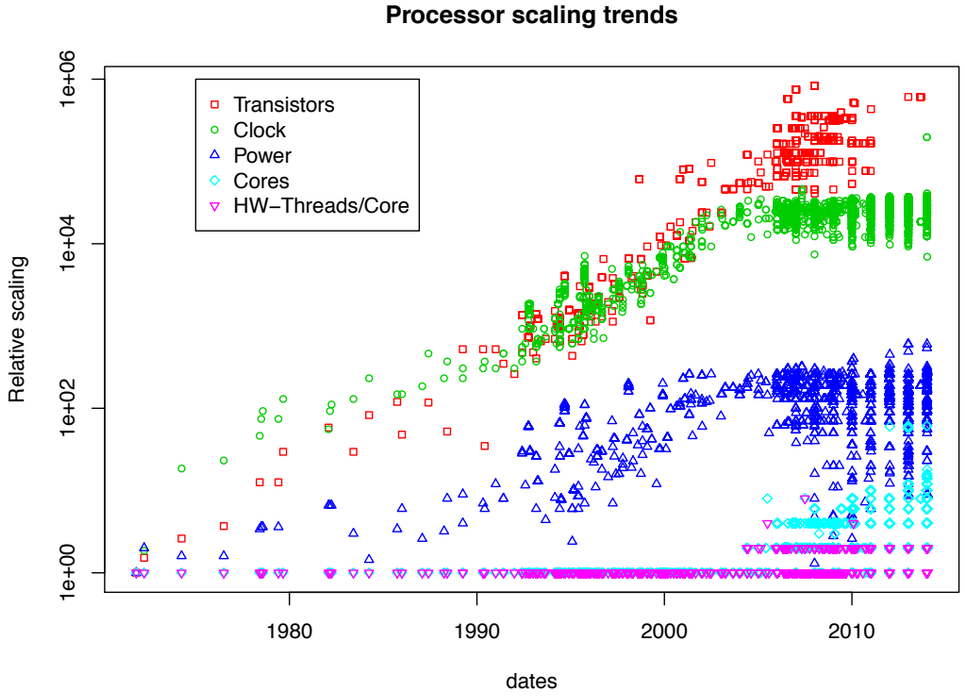
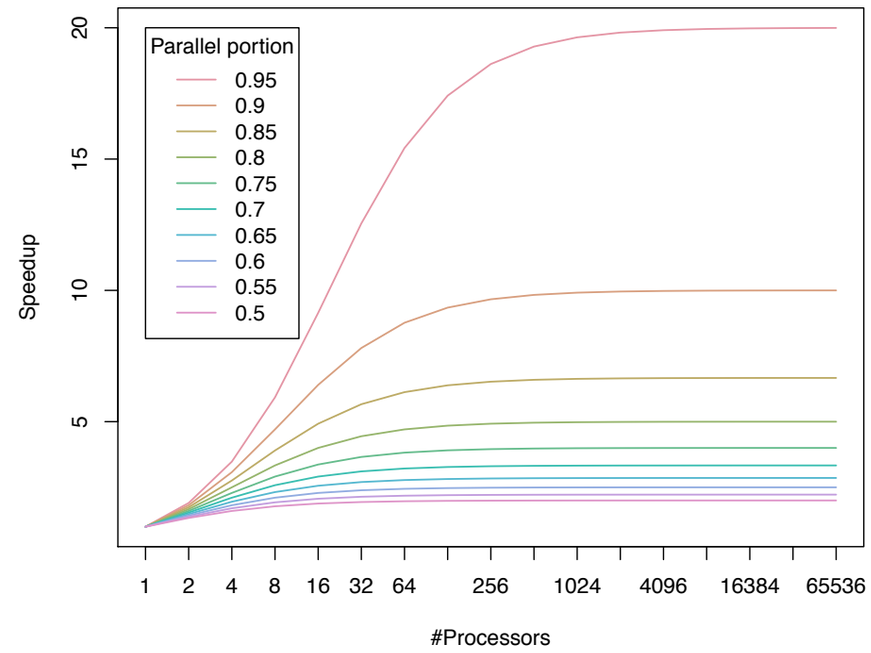
Tech Problem

Sebastian Ertel

My Tech Problem of the last years: Implicit Parallel Programming





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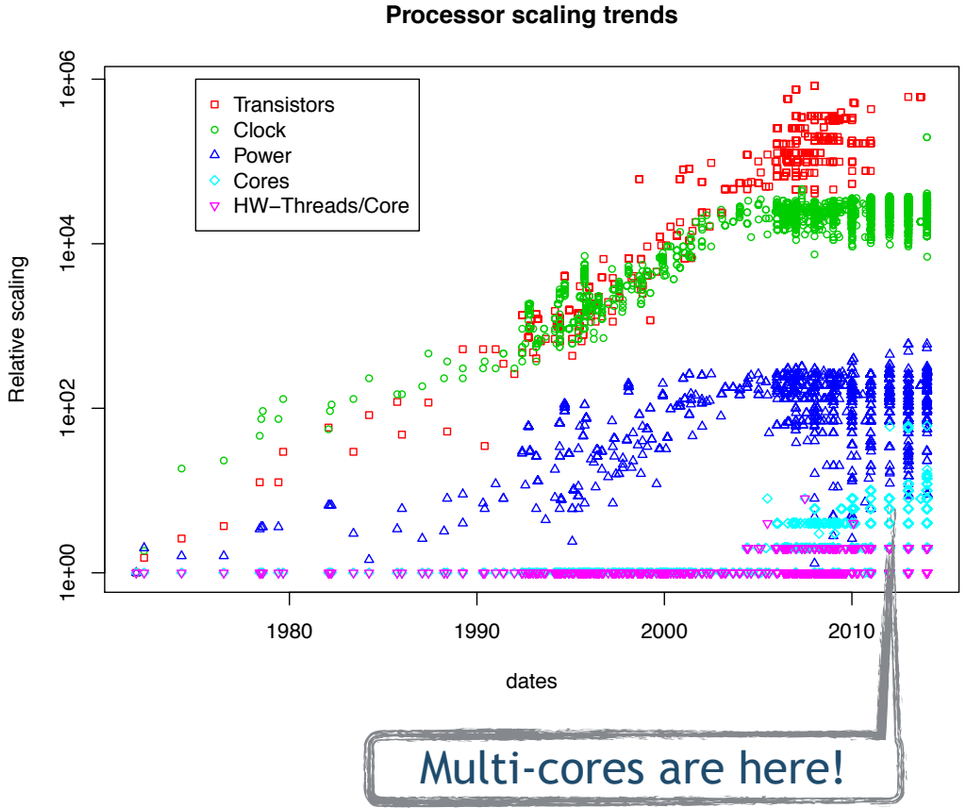
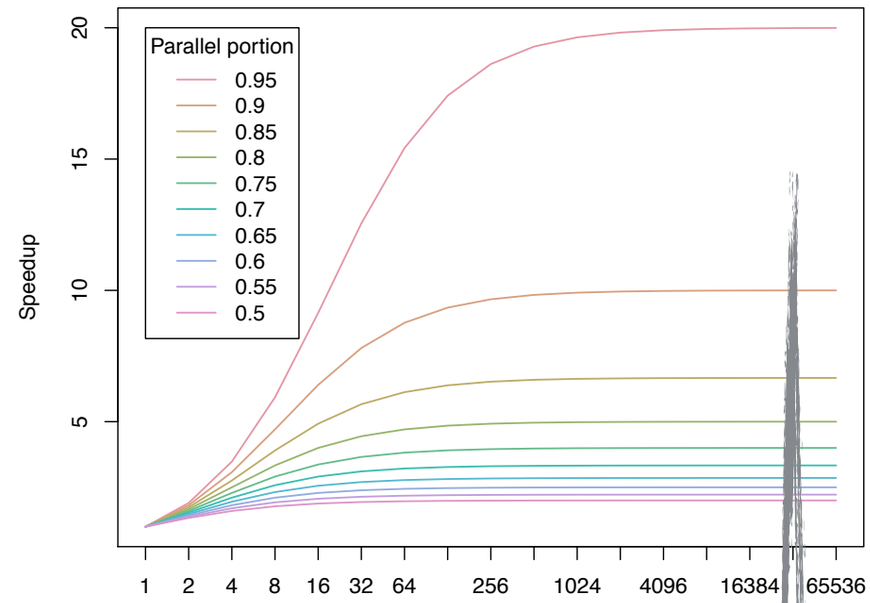
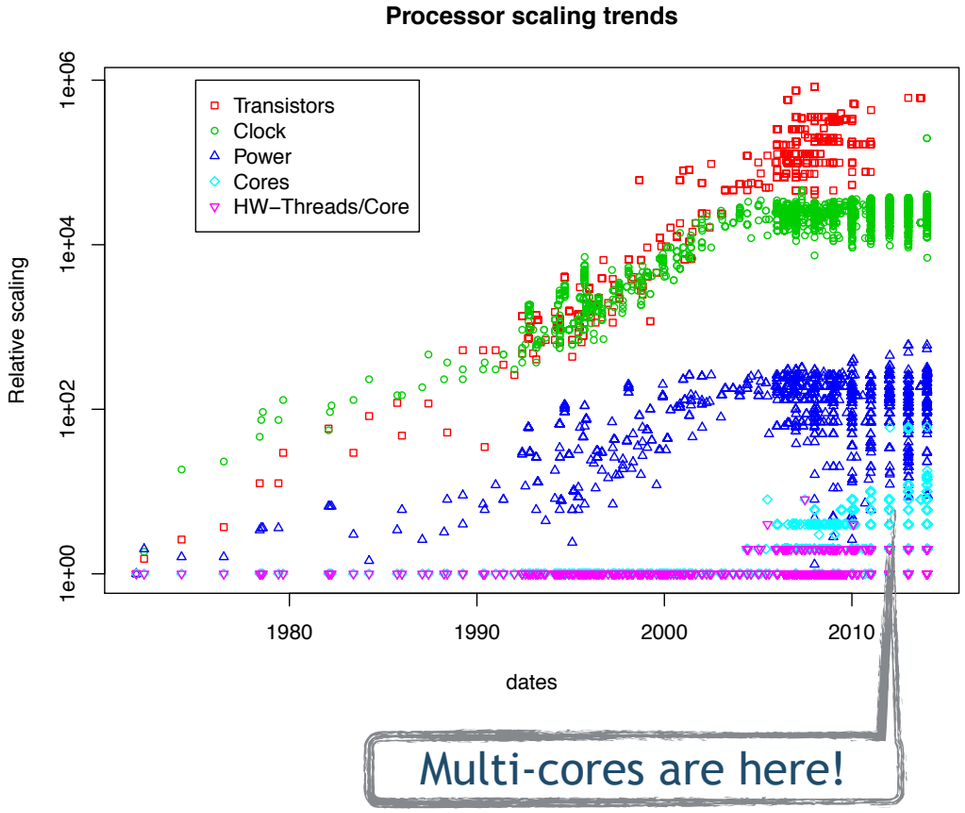


Multi-cores are here!



Squeeze out parallelism!

My Tech Problem of the last years: Implicit Parallel Programming



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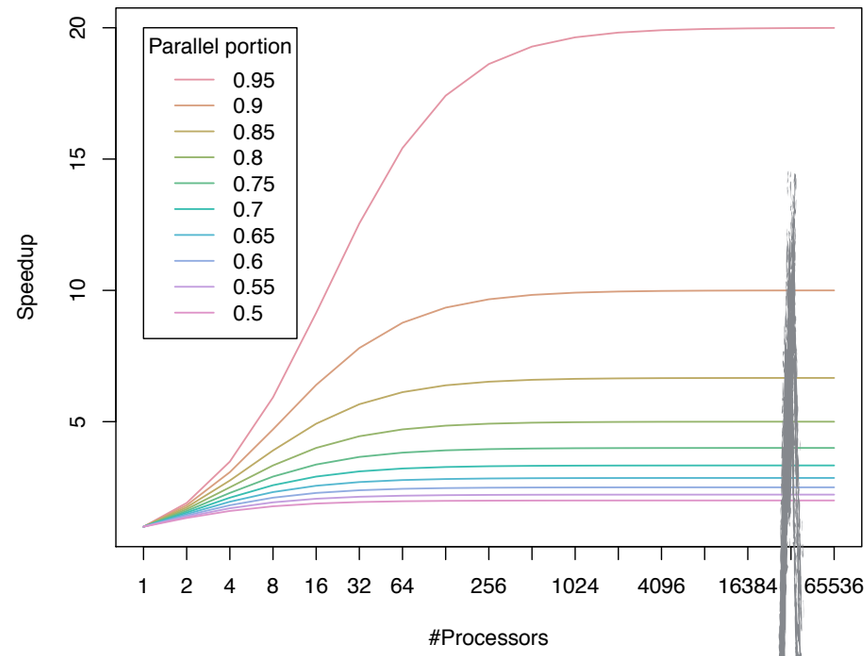

Squeeze out parallelism!

Parallel programming is hard!

- ➪ Manually introduce concurrency.
- ➪ Shared memory: data races.
- ➪ Threads/locks: deadlocks.

Programming Model

```
fn server(port:int) {
  let parse_state = init_parse_state();

  let acceptor = init_server(port);
  for cnn in acceptor {
    let data = read(cnn);
    let req = parse_state.parse(data);
    let resp = if (is_get(req)) {
                 load(req)
               } else {
                 store(req)
               }
    reply(resp);
  };
}
```

Programming Model

Algorithms vs. Functions

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Stateless vs. Stateful Functions

Programming Model

Algorithms vs. Functions

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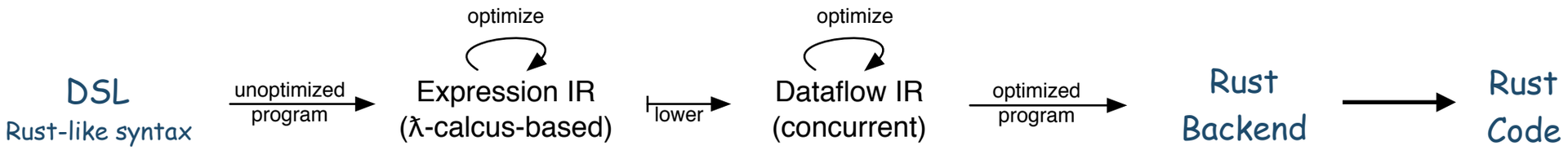
Stateless vs. Stateful Functions

Programming Model



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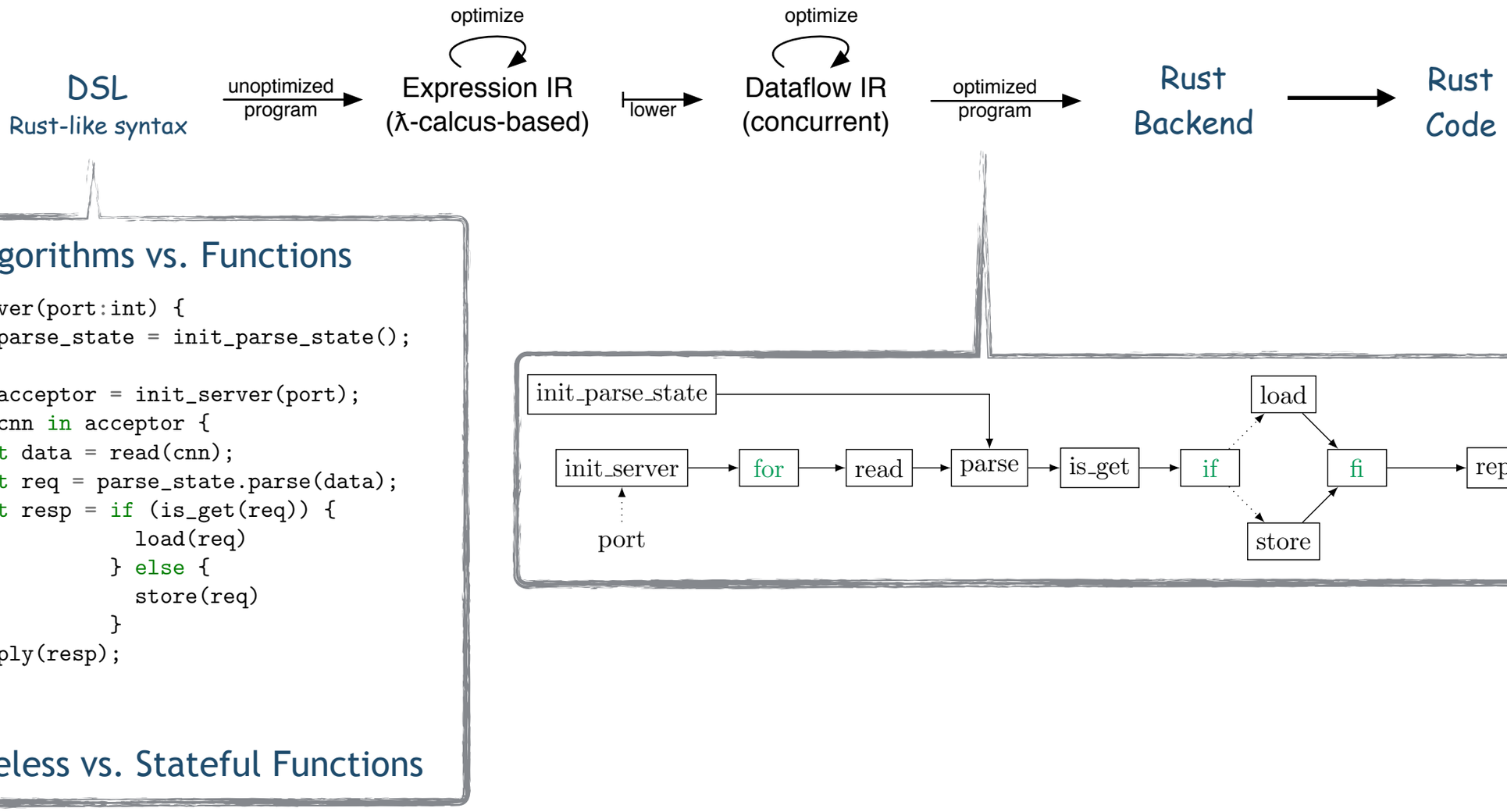
Stateless vs. Stateful Functions

➪ Broadly applicable!

➪ Algorithms as **higher-level abstractions!**

Programming Model



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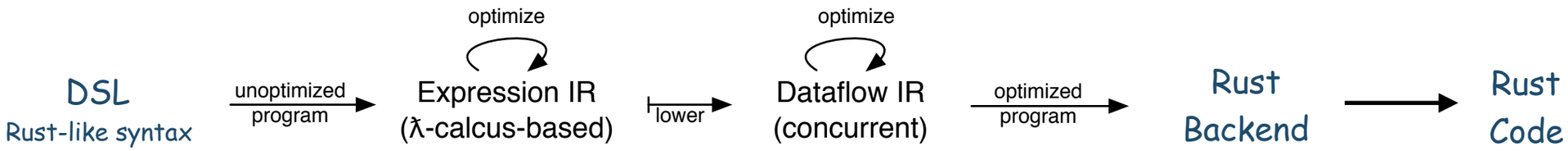
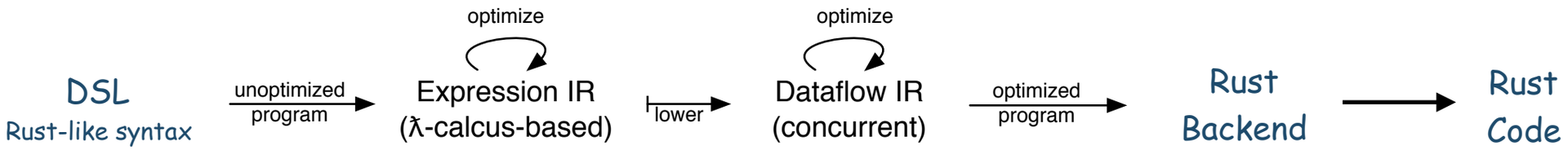
Programming Framework

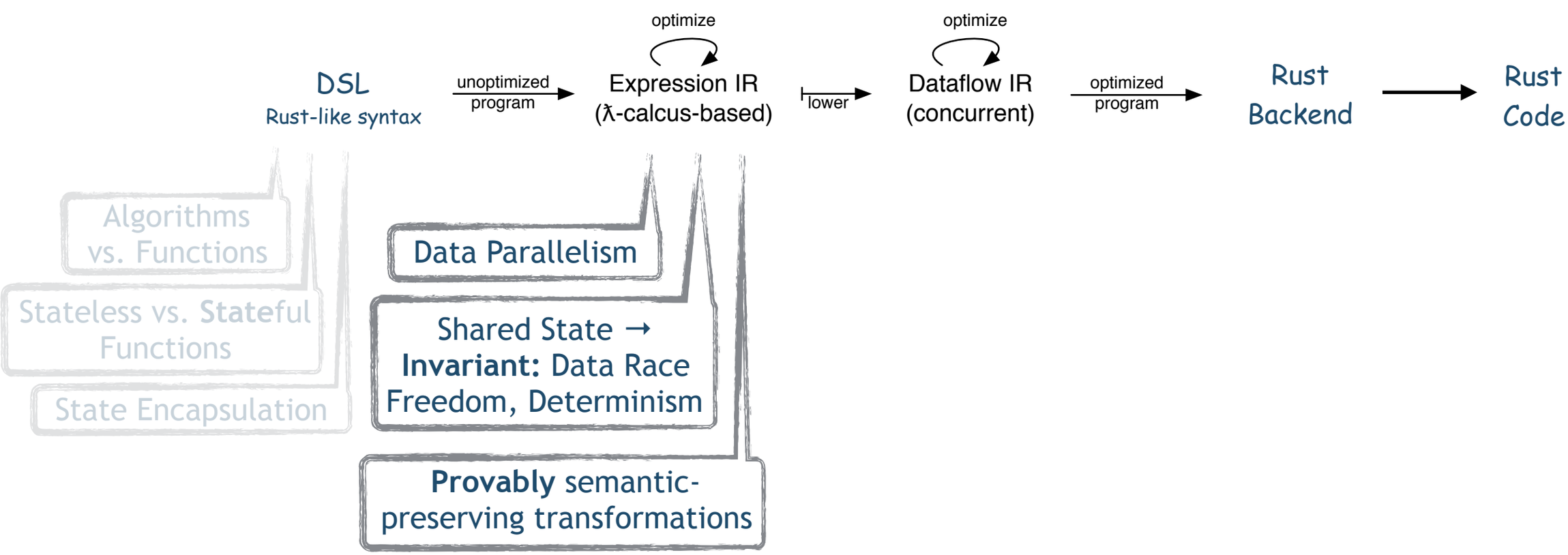


Programming Framework

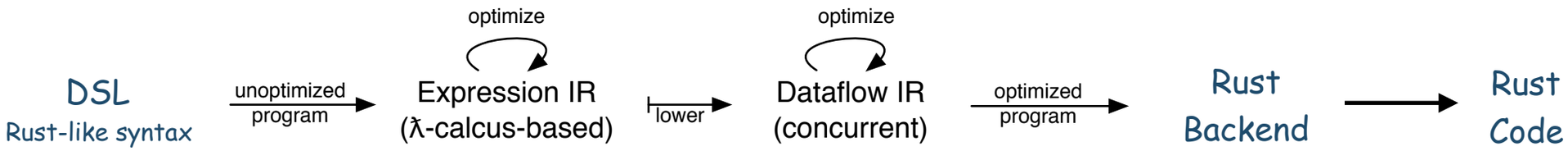


- Algorithms vs. Functions
- Stateless vs. **State**ful Functions
- State Encapsulation

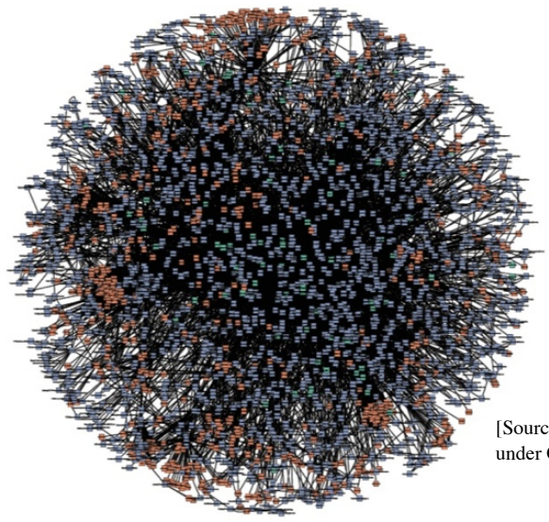
Programming Framework



Optimizing I/O of Micro-services



Monolithic server programs



amazon

http://amazon.com

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Micro-service-based systems

Ertel, S., Goens, A., Adam, J. and Castrillon, J., 2018, February. Compiling for concise code and efficient I/O. In *Proceedings of the 27th International Conference on Compiler Construction* (pp. 104-115). ACM.

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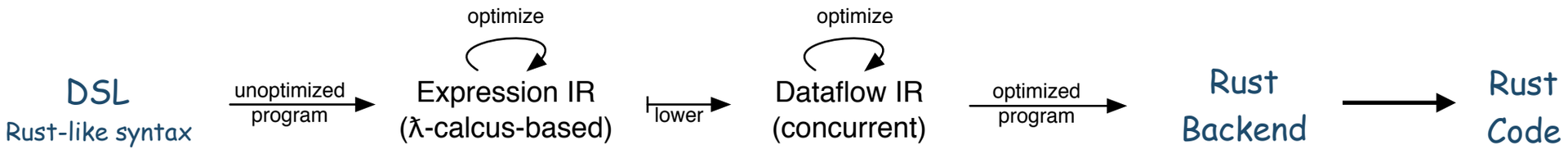

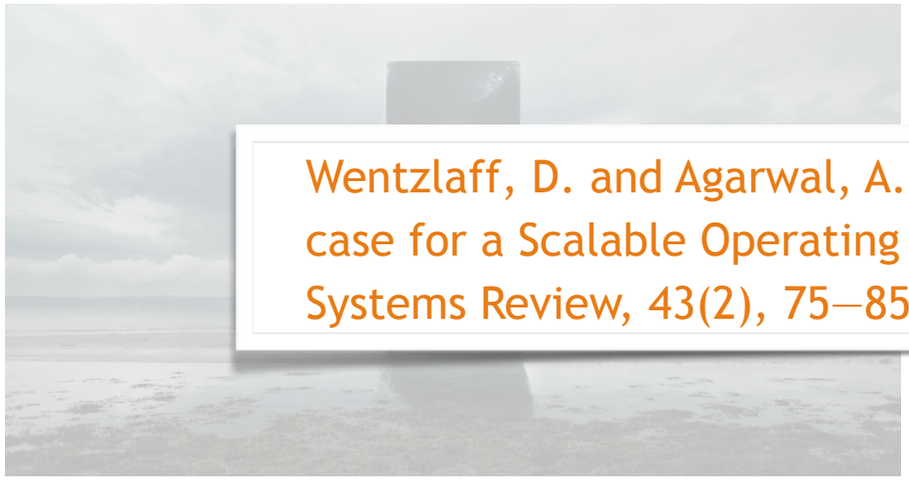

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Wentzlaff, D. and Agarwal, A., (2009). Factored Operating Systems (fos): The case for a Scalable Operating System for Multicores. ACM SIGOPS Operating Systems Review, 43(2), 75—85

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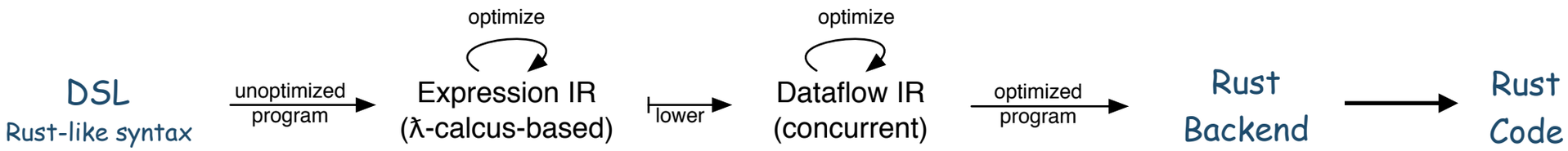
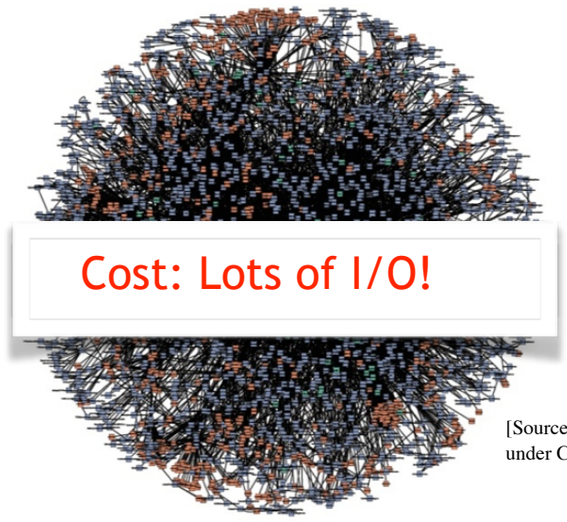


Monolithic server programs



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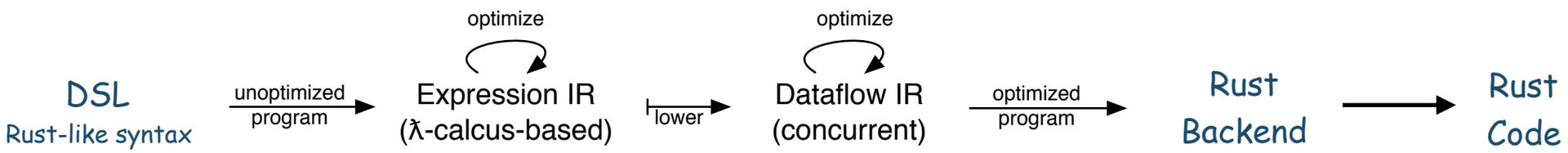

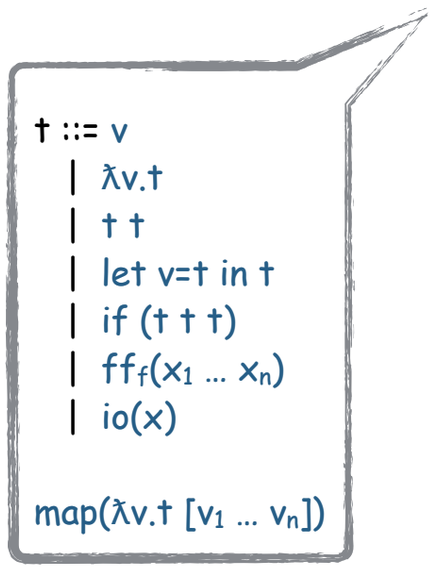

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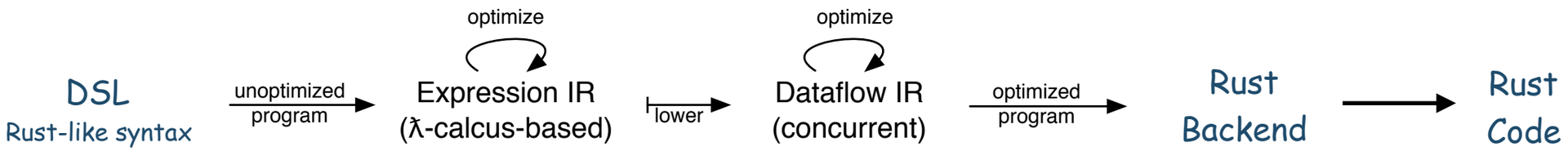

t ::= x
| $TT_f(x_1 \dots x_n)$
| io(x)

map(λv.t $[v_1 \dots v_n]$)

Disclaimer: Presentation diverges (from paper) for visualization purposes. Data flow graphs before and after the transformations instead of lambda expressions.

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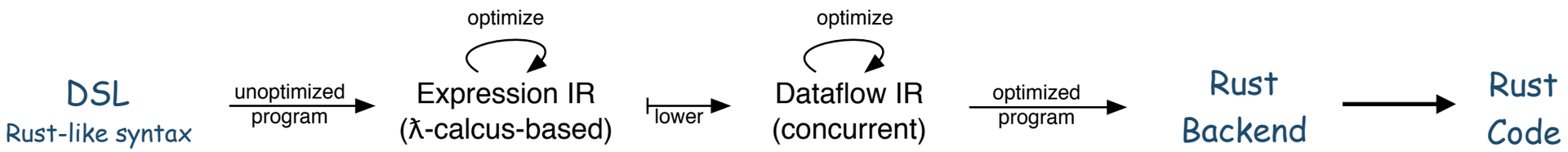

t ::= v
| λv.t
| t t
| let v=t in t
| if (t t t)
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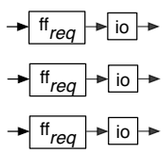
- Grouping independent I/O calls:



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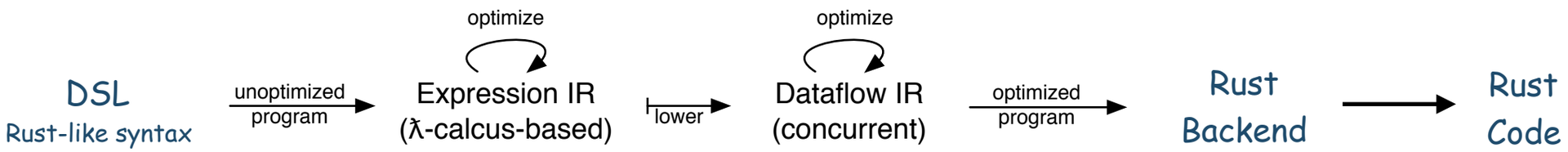

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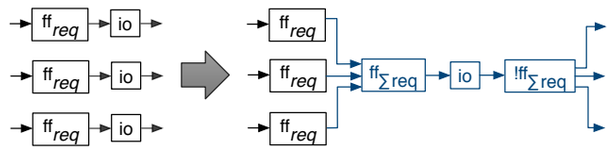

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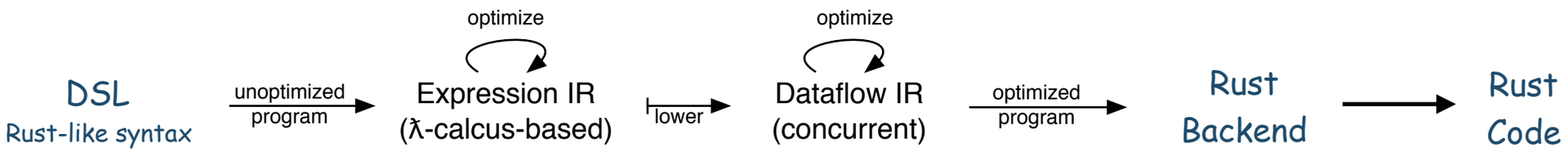
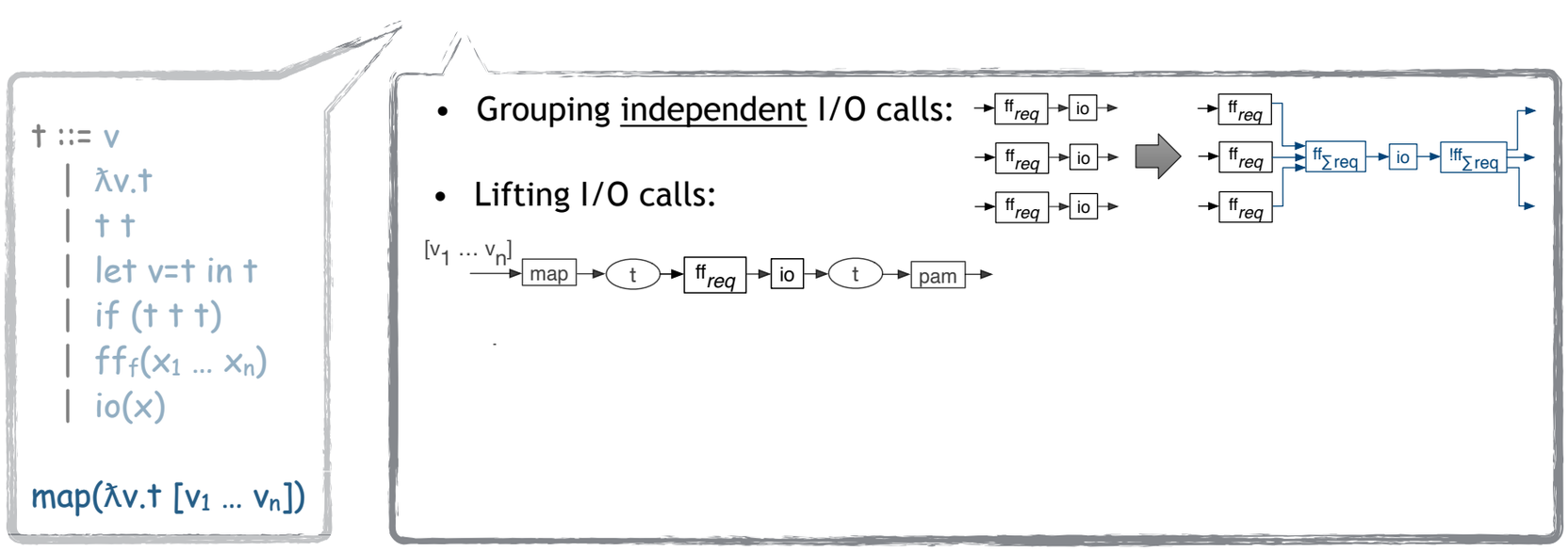
Optimizing I/O of Micro-services





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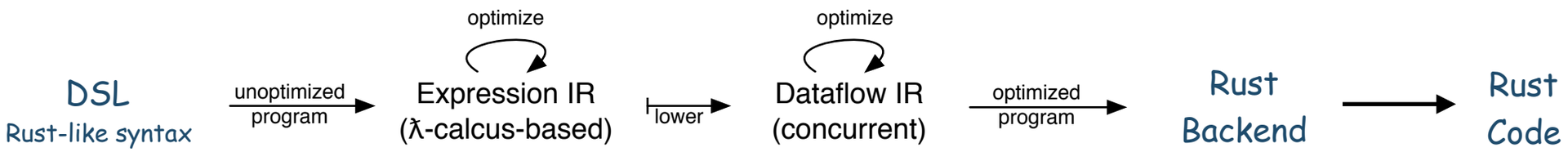

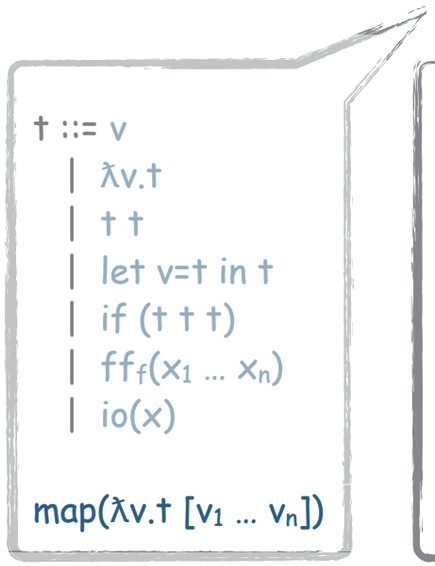

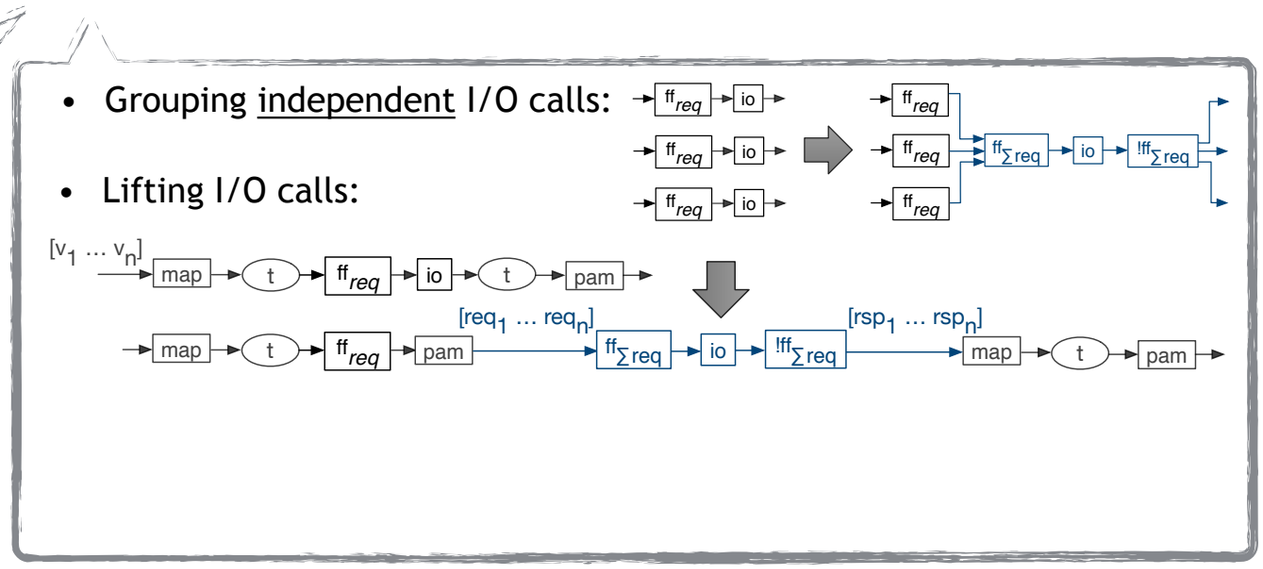

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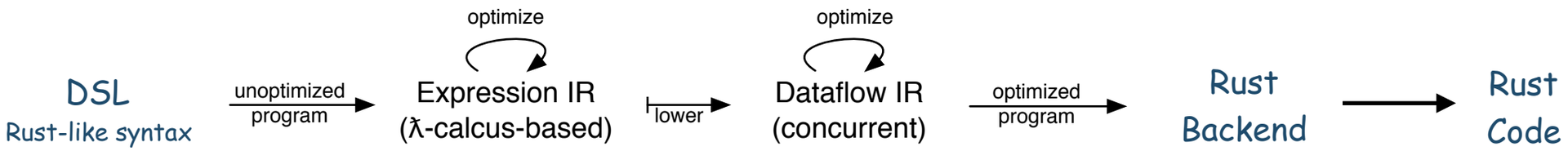

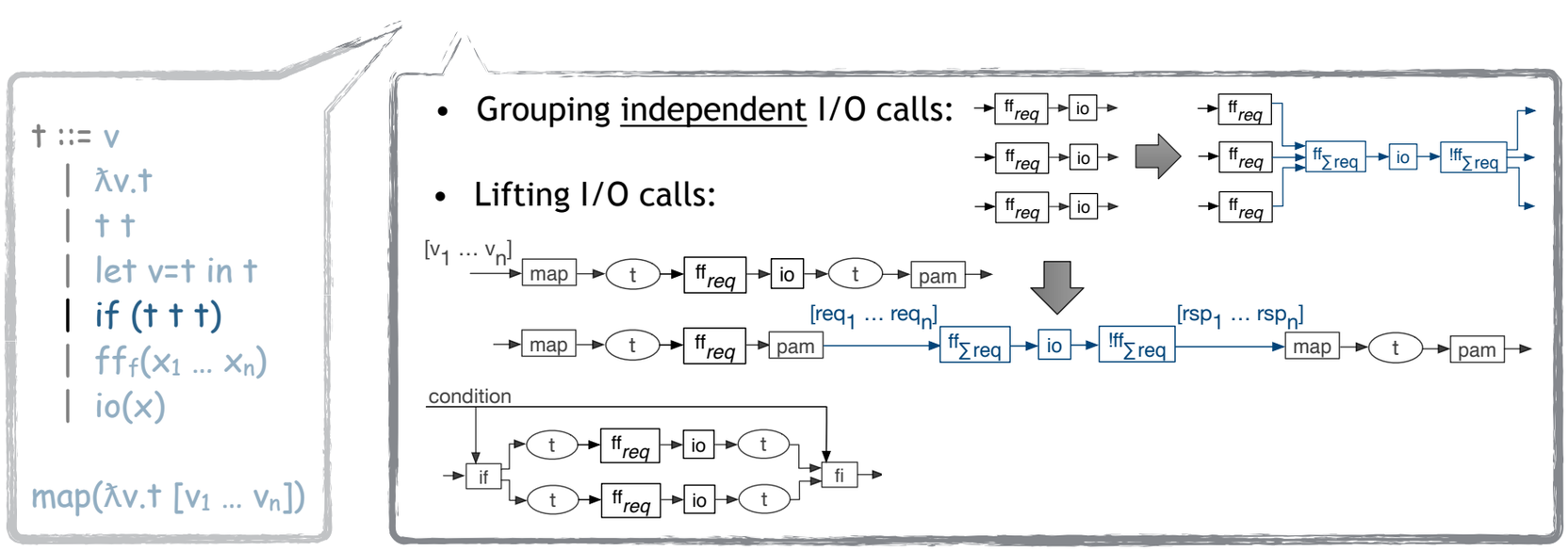

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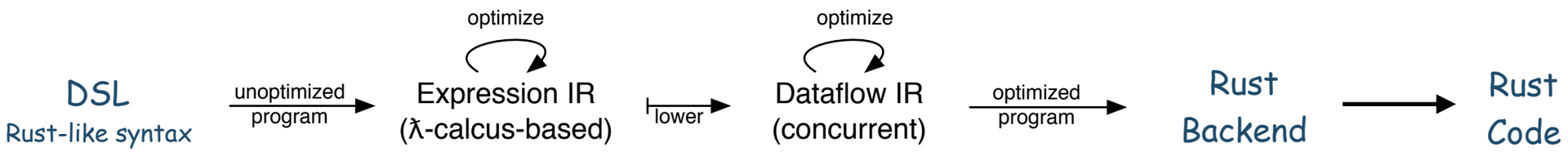

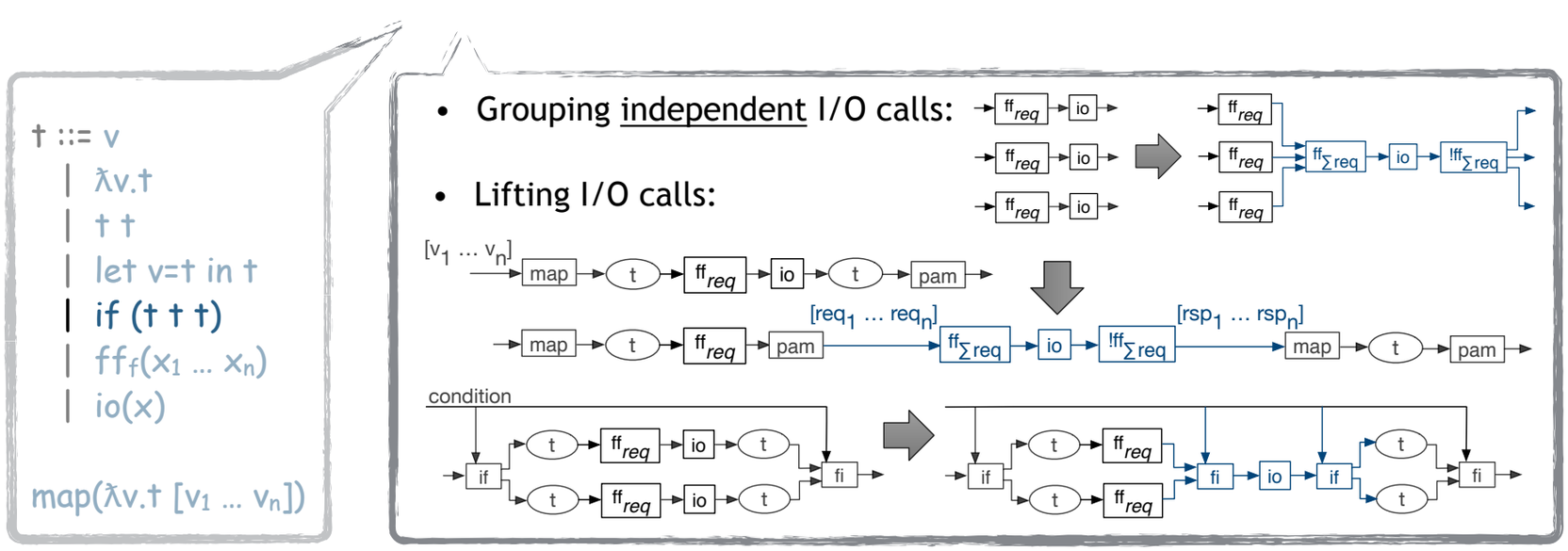

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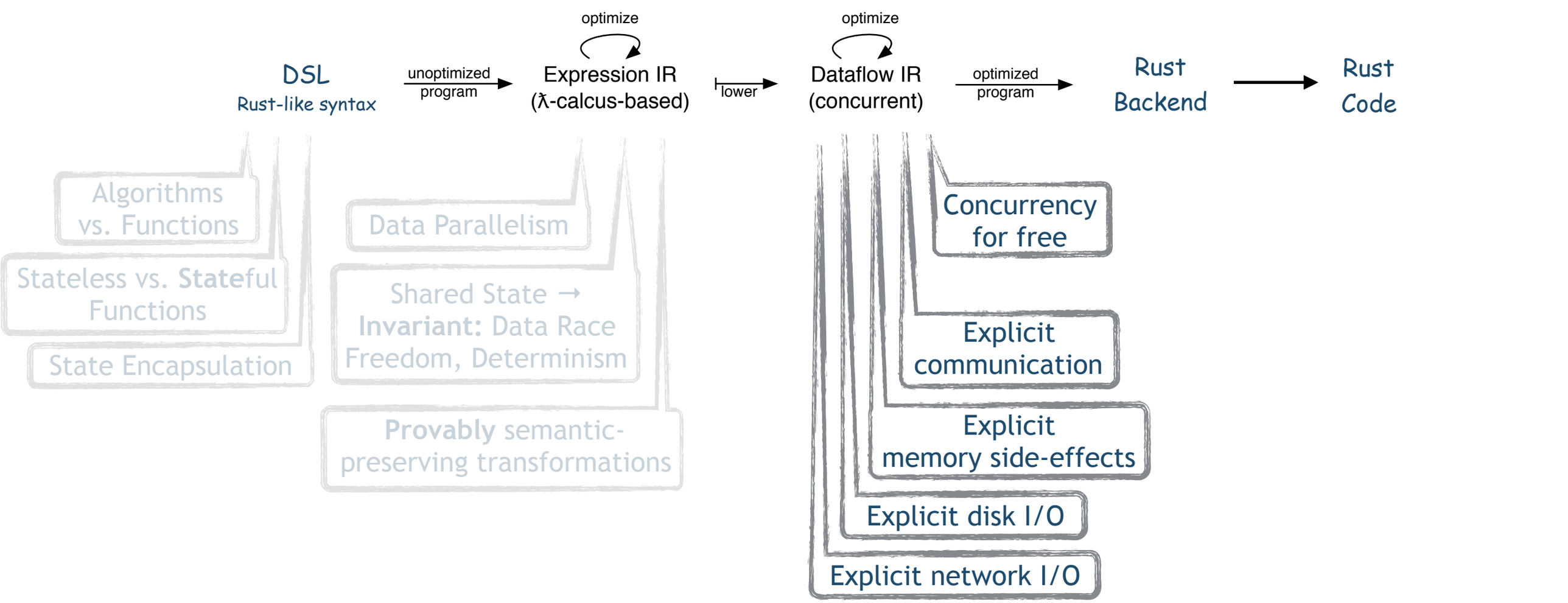
Programming Framework



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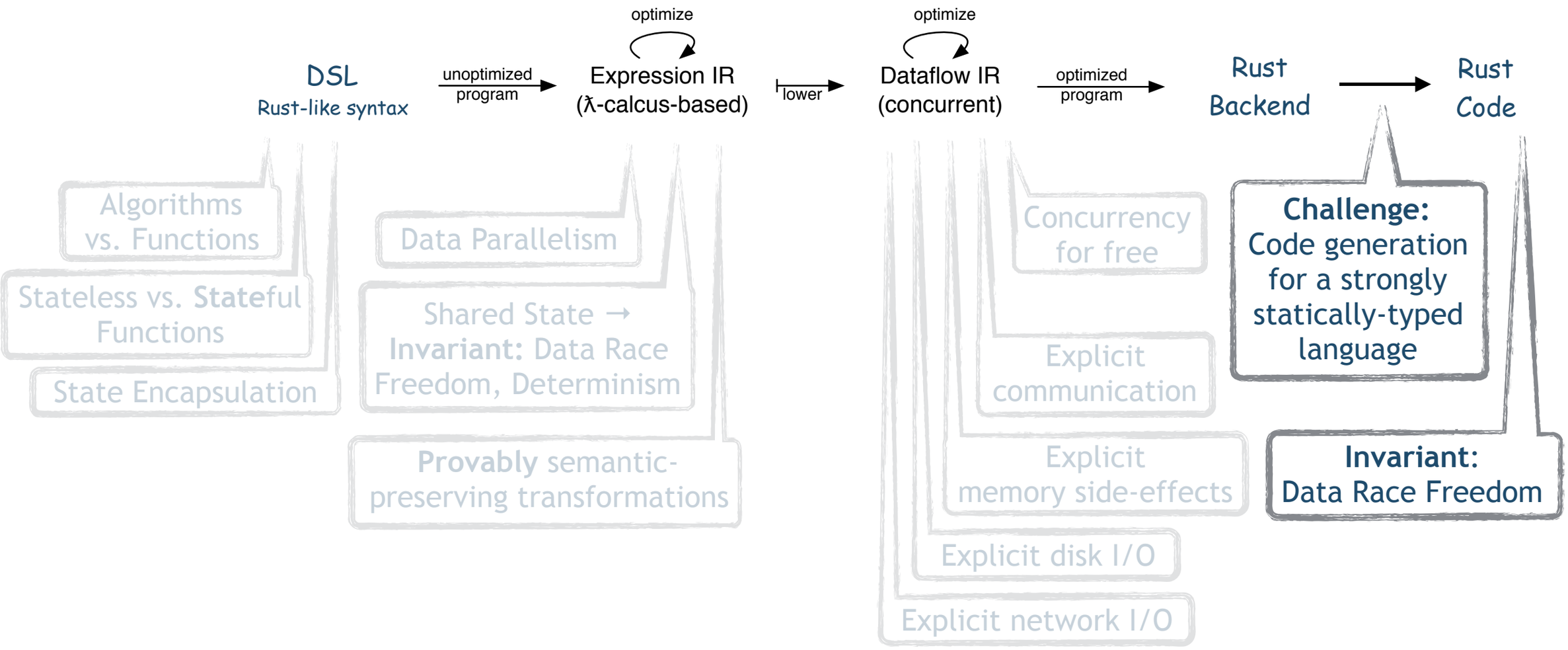
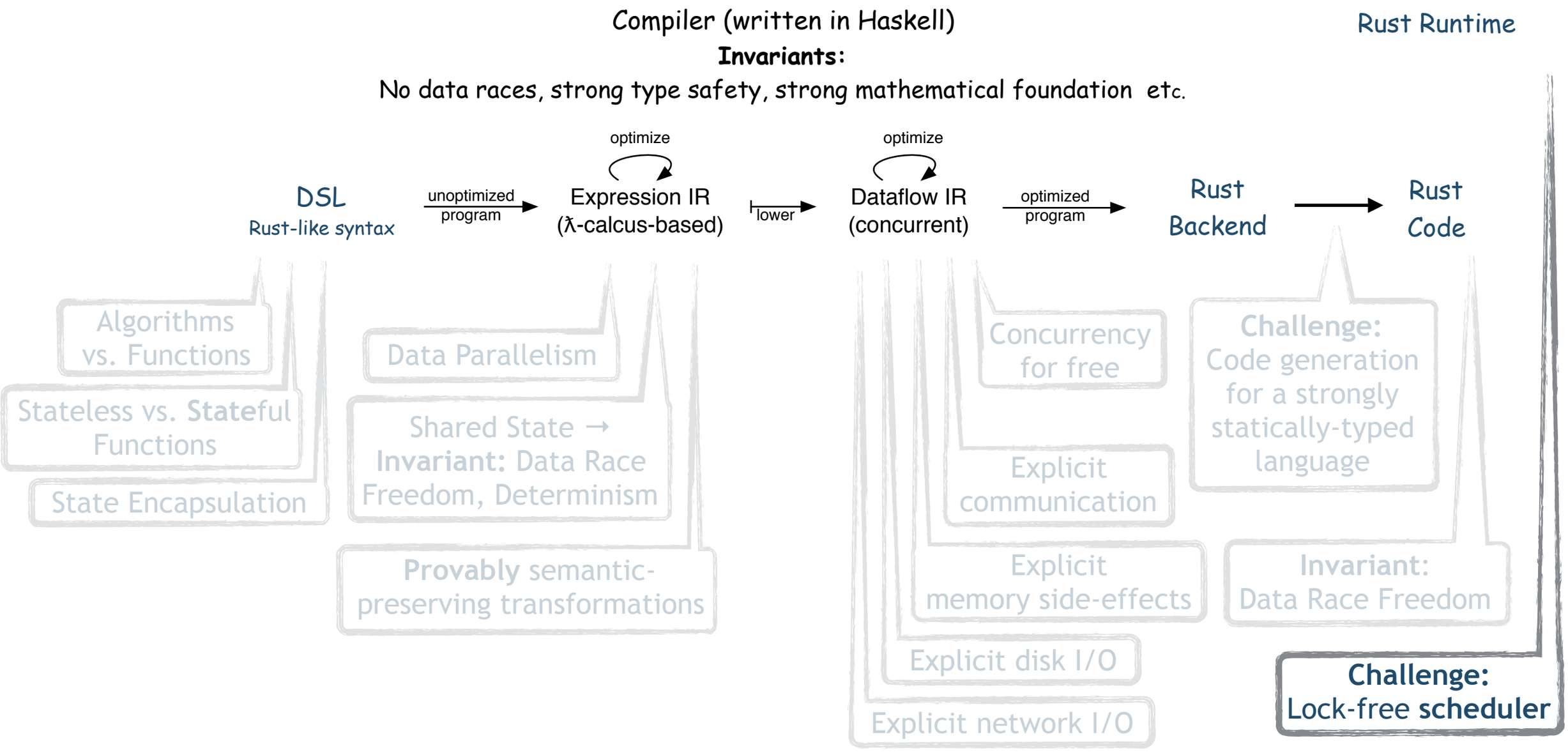


Programming Framework



How does that relate to OS design?

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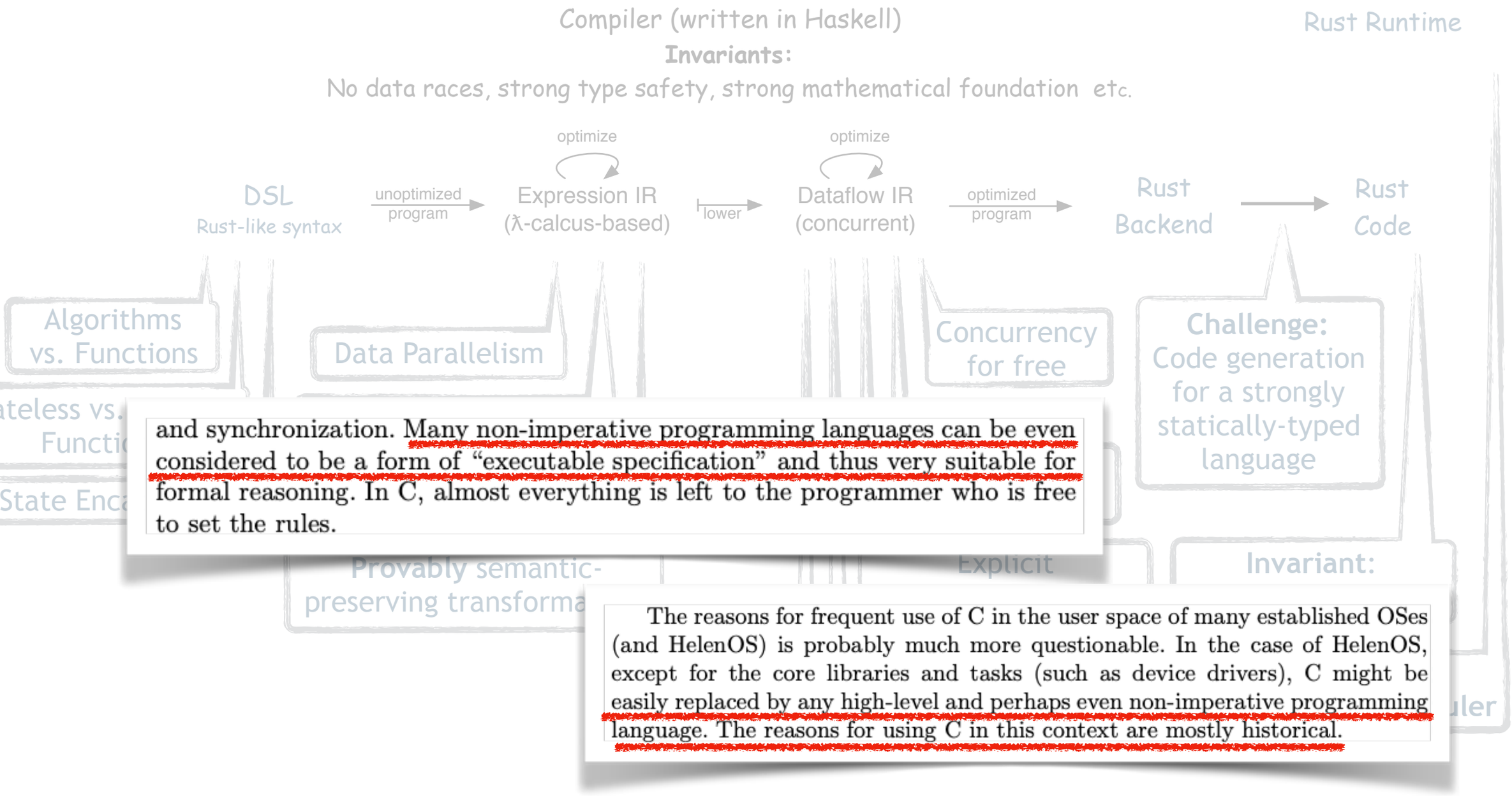
(I think so but better you tell me!)

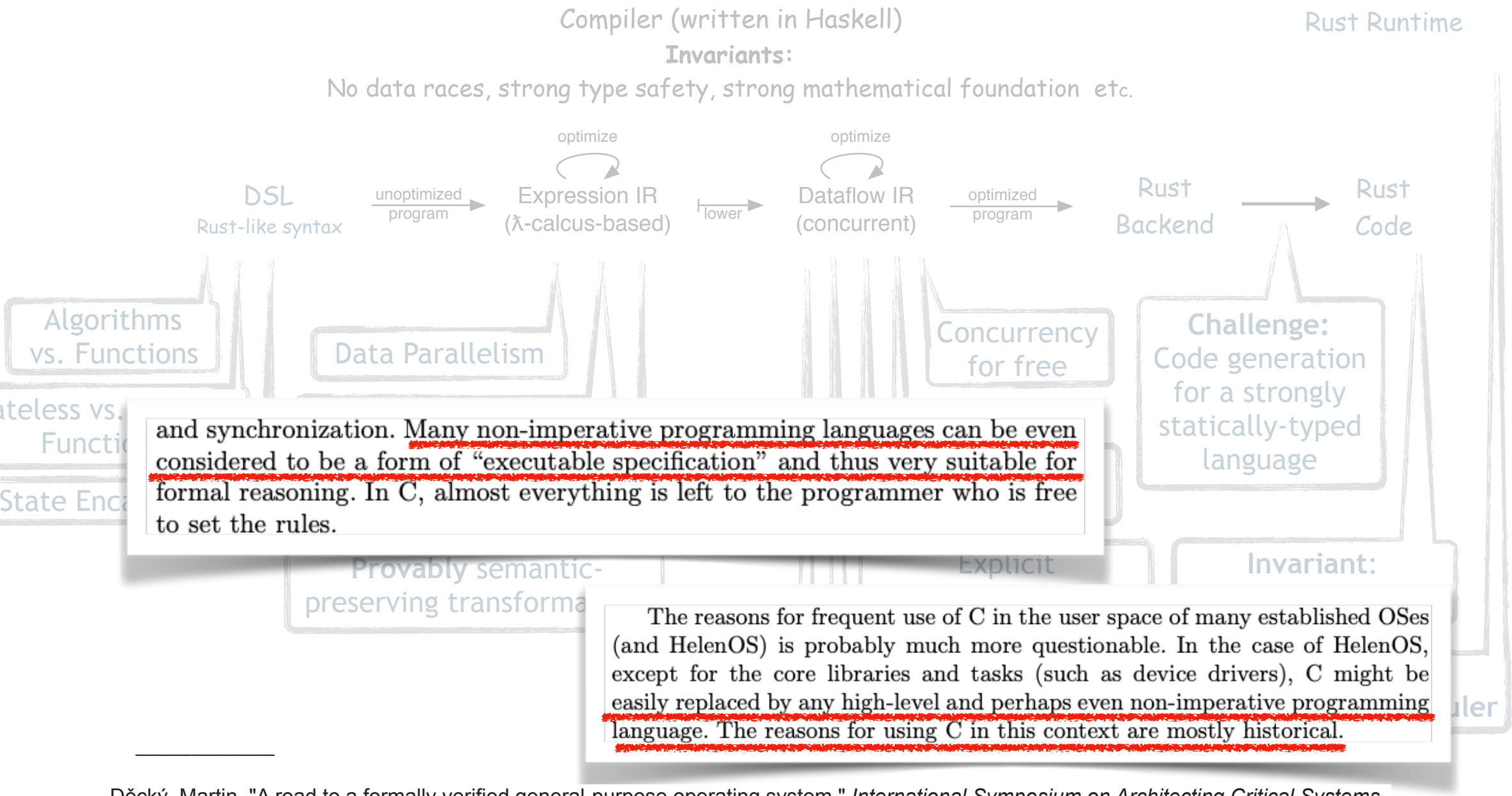
Go Functional!



and synchronization. Many non-imperative programming languages can be even considered to be a form of "executable specification" and thus very suitable for formal reasoning. In C, almost everything is left to the programmer who is free to set the rules.

The reasons for frequent use of C in the user space of many established OSes (and HelenOS) is probably much more questionable. In the case of HelenOS, except for the core libraries and tasks (such as device drivers), C might be easily replaced by any high-level and perhaps even non-imperative programming language. The reasons for using C in this context are mostly historical.

Go Functional!



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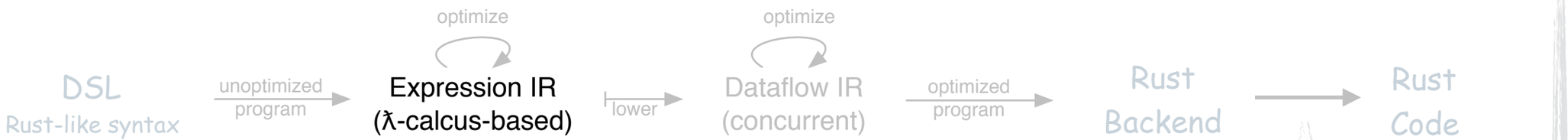
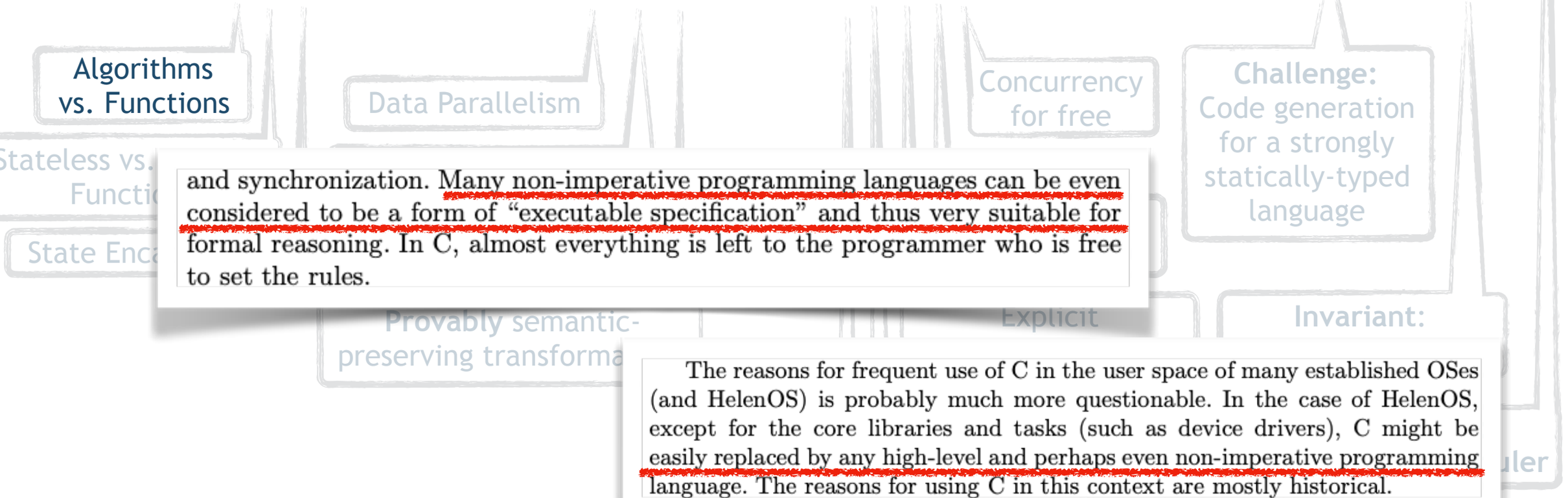
Go Functional!

Compiler (written in Haskell)

Invariants:

No data races, strong type safety, strong mathematical foundation etc.





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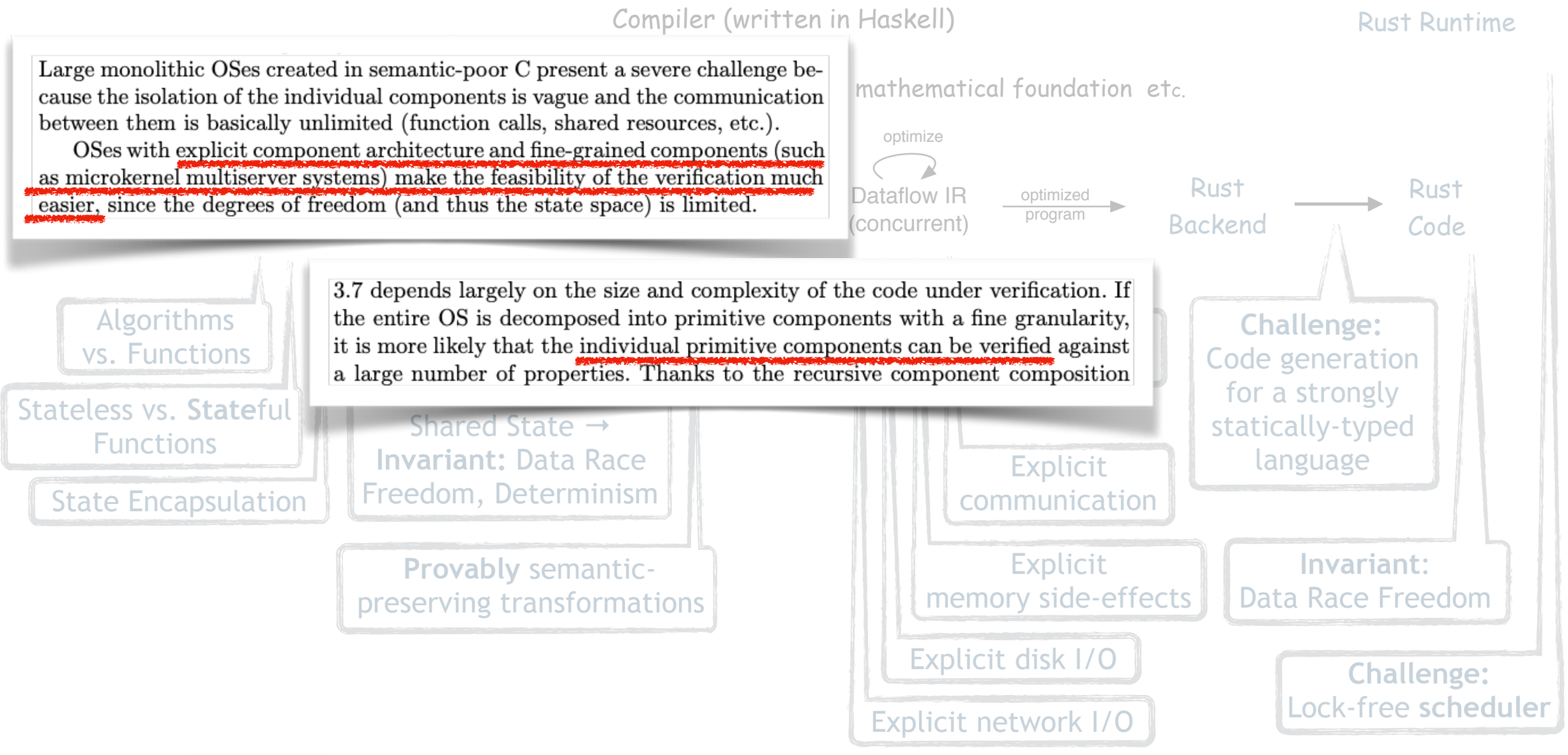
Decomposition for Verification!

Large monolithic OSes created in semantic-poor C present a severe challenge because the isolation of the individual components is vague and the communication between them is basically unlimited (function calls, shared resources, etc.).

OSes with explicit component architecture and fine-grained components (such as microkernel multiserver systems) make the feasibility of the verification much easier, since the degrees of freedom (and thus the state space) is limited.

3.7 depends largely on the size and complexity of the code under verification. If the entire OS is decomposed into primitive components with a fine granularity, it is more likely that the individual primitive components can be verified against a large number of properties. Thanks to the recursive component composition



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Decomposition for Verification!

Compiler (written in Haskell)

Rust Runtime

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optimize

Dataflow IR (concurrent)

optimized program

Rust Backend

Rust Code

Challenge: Code generation for a strongly statically-typed language

Algorithms vs. Functions

Stateless vs. Stateful Functions

State Encapsulation

Shared State → **Invariant:** Data Race Freedom, Determinism

Provably semantic-preserving transformations

Explicit communication

Explicit memory side-effects

Explicit disk I/O

Explicit network I/O

Invariant: Data Race Freedom

Challenge: Lock-free scheduler

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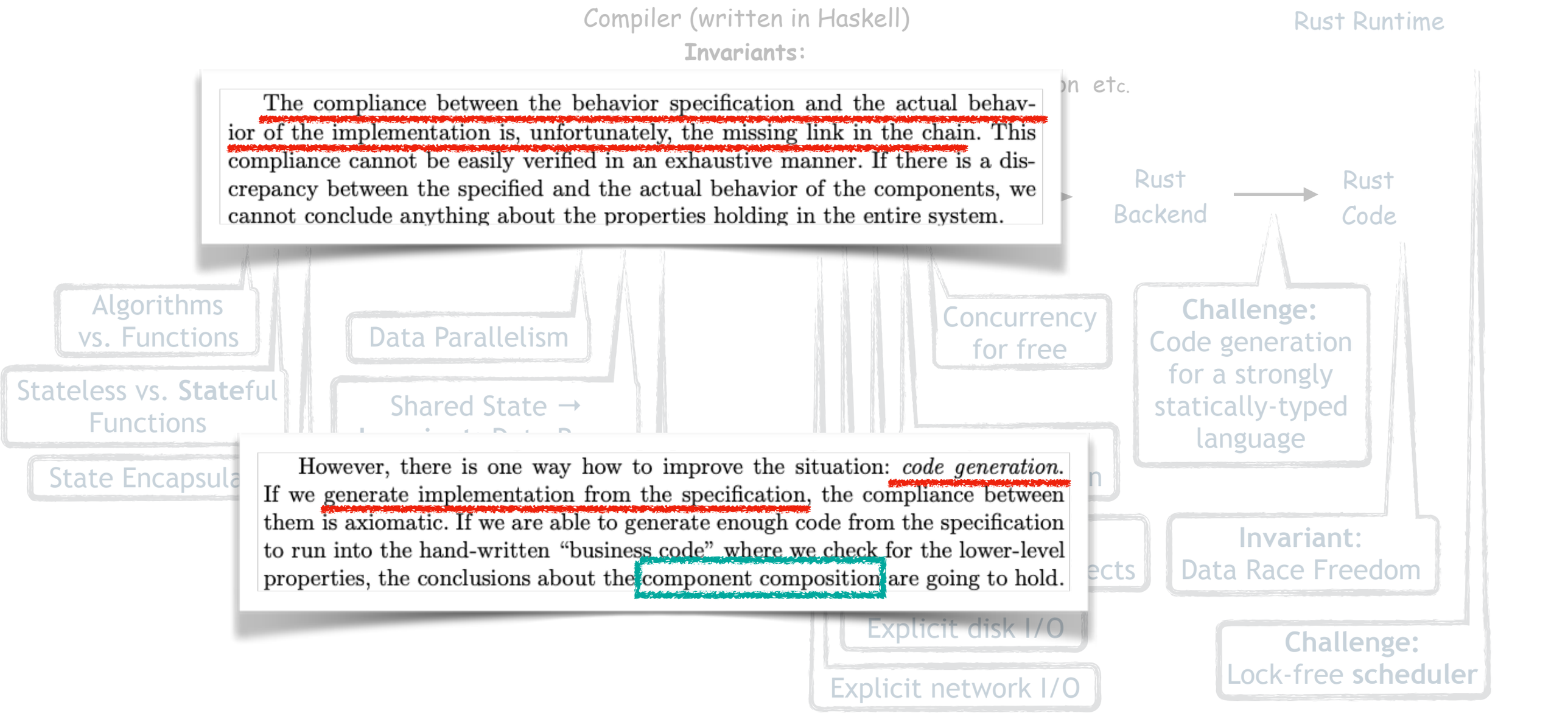
Code Generation needed!



> The compliance between the behavior specification and the actual behavior of the implementation is, unfortunately, the missing link in the chain. This compliance cannot be easily verified in an exhaustive manner. If there is a discrepancy between the specified and the actual behavior of the components, we cannot conclude anything about the properties holding in the entire system.

> However, there is one way how to improve the situation: *code generation*. If we generate implementation from the specification, the compliance between them is axiomatic. If we are able to generate enough code from the specification to run into the hand-written "business code", where we check for the lower-level properties, the conclusions about the component composition are going to hold.

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Rust Runtime

etc.

Rust Backend → Rust Code

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Data Parallelism

Shared State →

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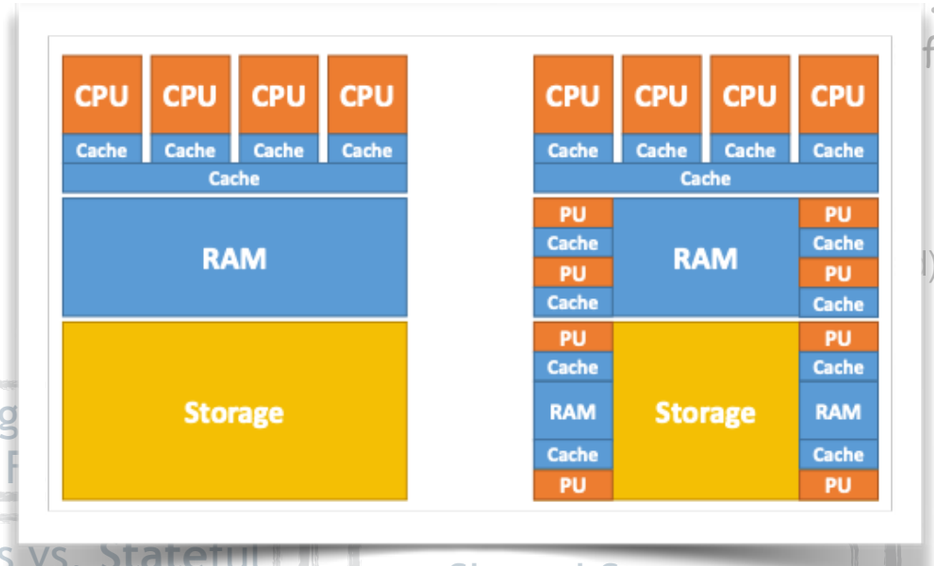
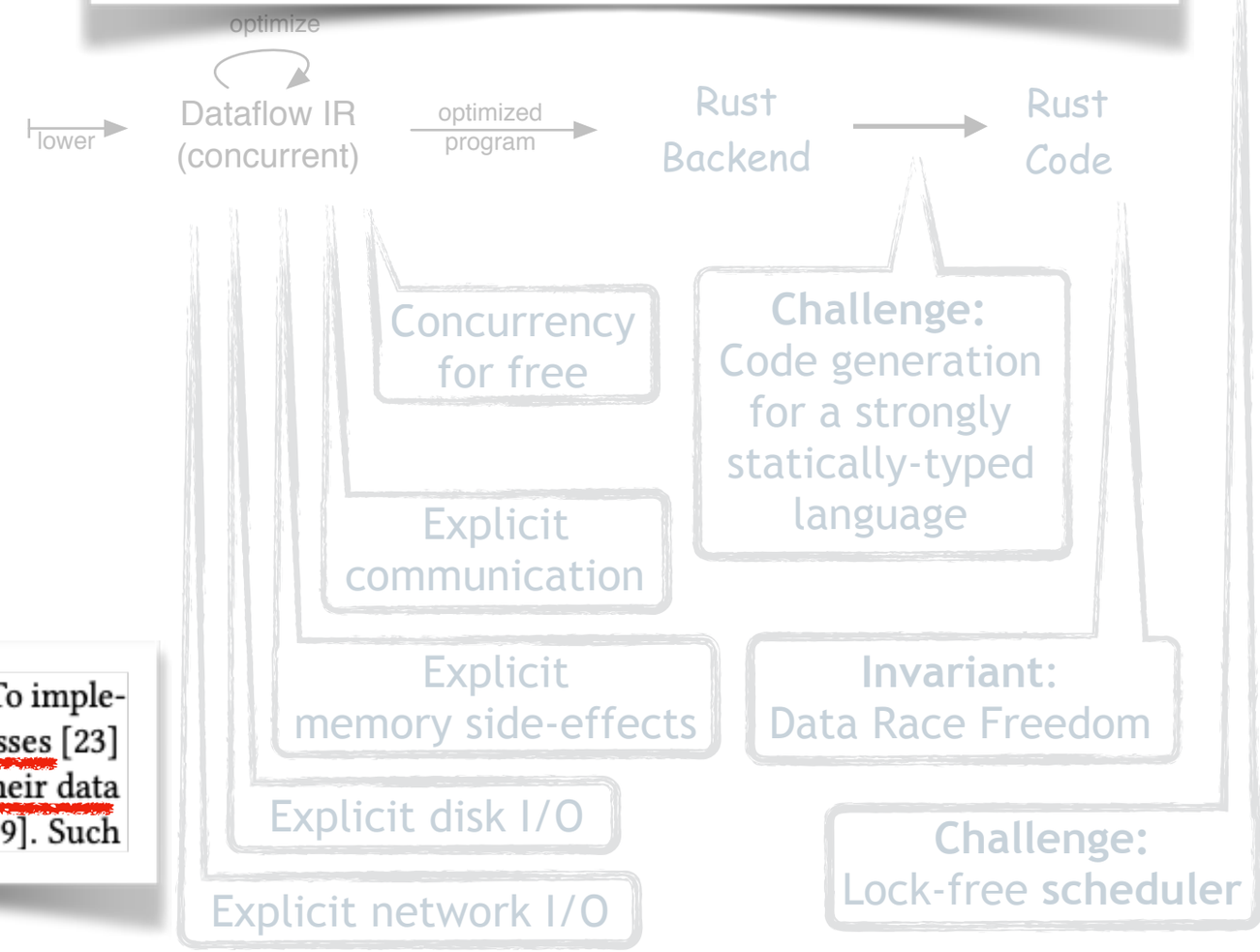
Knowledge is power!



balance or minimize energy consumption. At the same time, a key objective of scheduling is to minimize data movements, favoring code migration instead. This goes behind the NUMA functionalities



NUMA zone to which their data have been allocated [21]. To implement data-driven scheduling we propose to track data accesses [23] as well as augment applications with information about their data access pattern, for example in the binary executable itself [9]. Such

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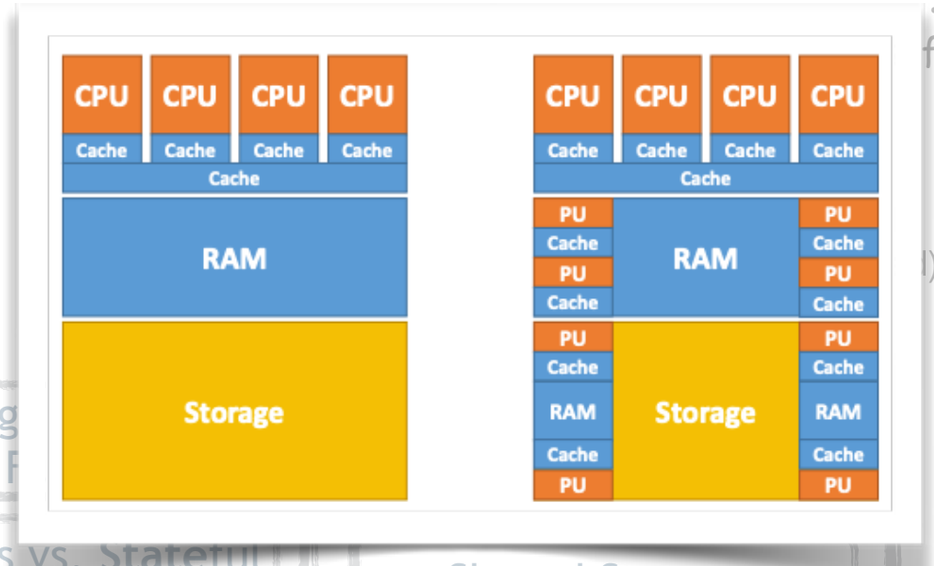

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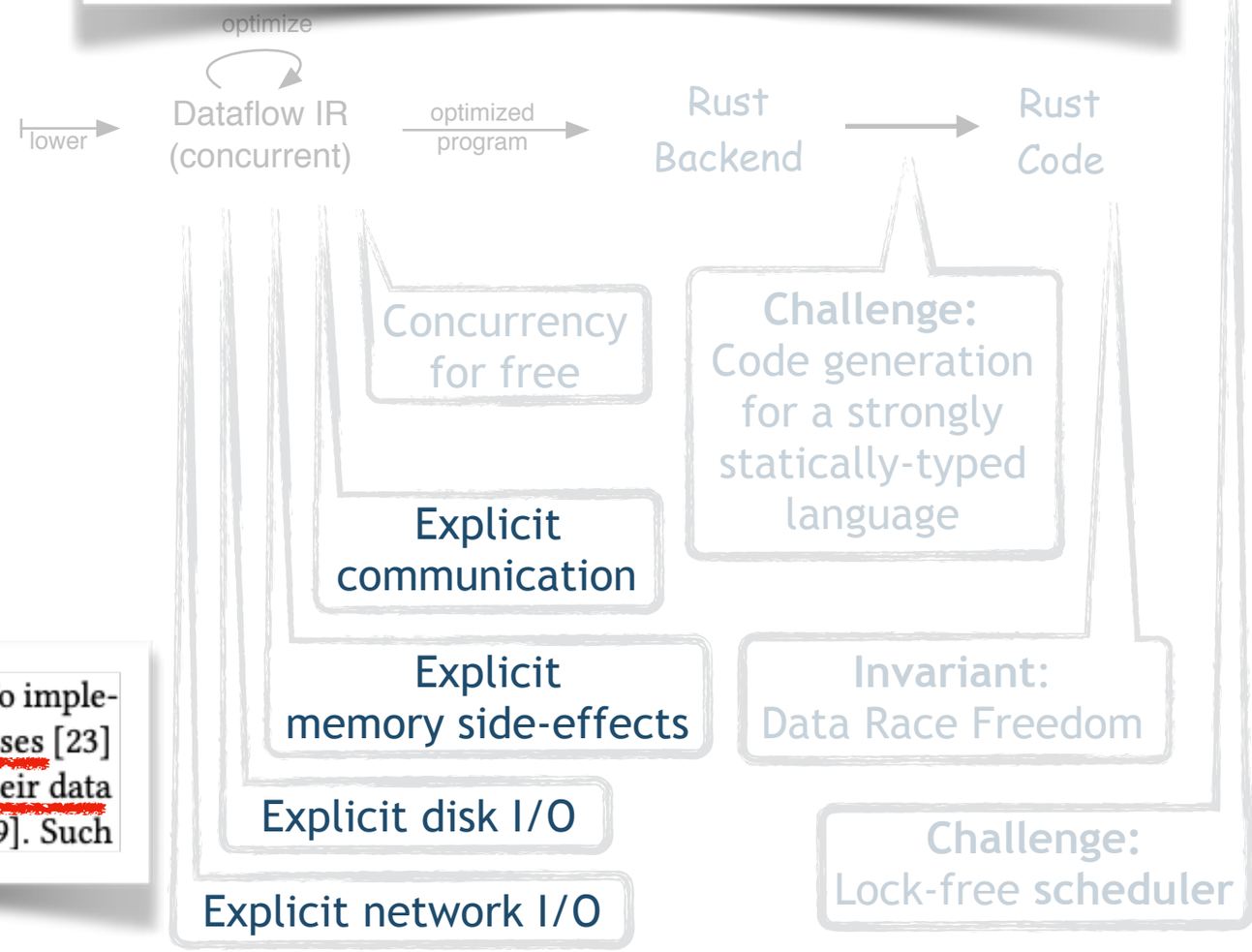

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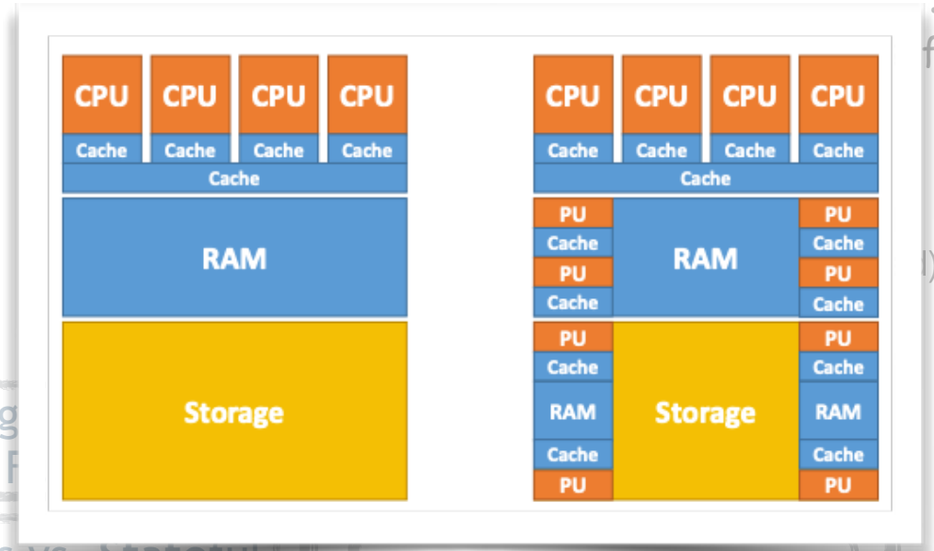

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lower

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optimized program

Rust Backend

Rust Code

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Explicit communication

Explicit memory side-effects

Explicit disk I/O

Explicit network I/O

language

Invariant: Data Race Freedom

Challenge: Lock-free scheduler

Shared State →
Invariant: Data Race Freedom, Determinism

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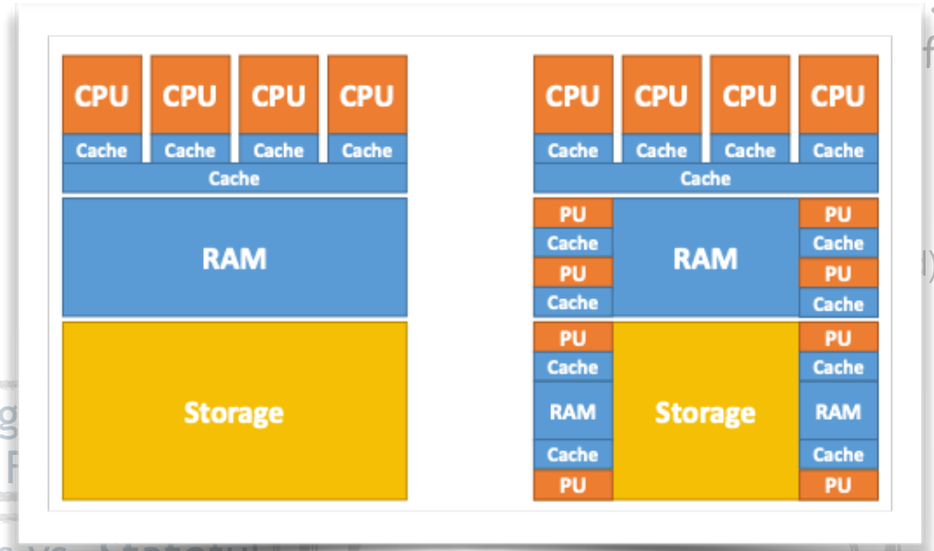

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Final Take-away Points

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Let’s join forces!

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I don’t have the traditional kernel construction knowledge.

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But:
Are you really looking for that in order to rethink kernel design?!