CONTINUOUS DEEP ANALYTICS (2018-2023)

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distr. computing

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New MSc/PhDs

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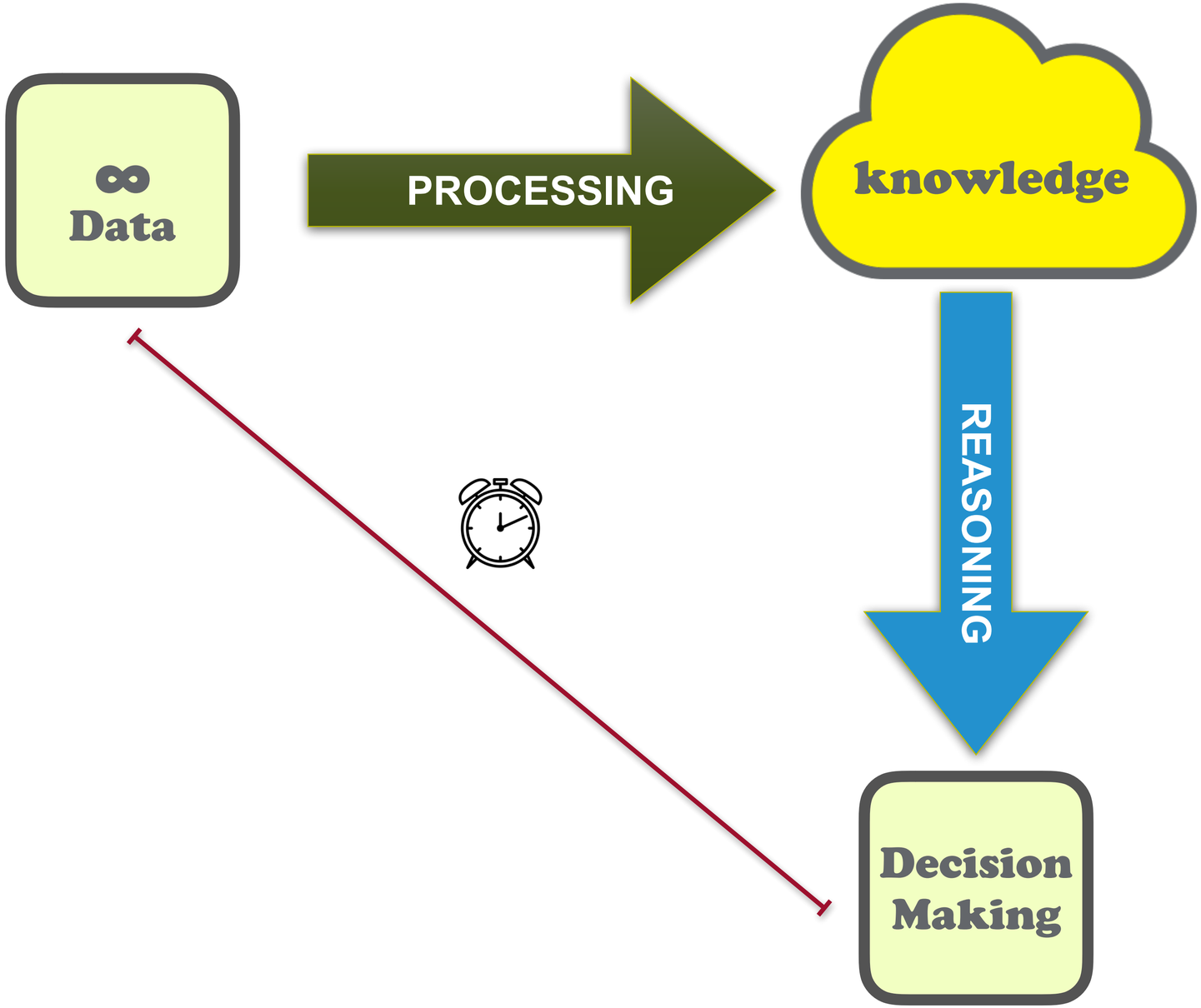
- **Max Meldrum**

- **Oscar Bjuhr**
- **Johan Mickos**


∞
Data
PROCESSING
knowledge
REASONING
Decision Making

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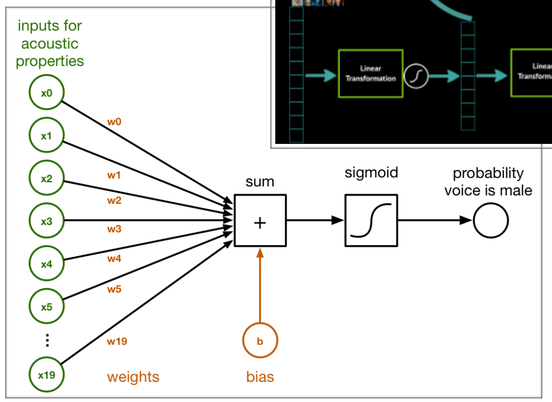
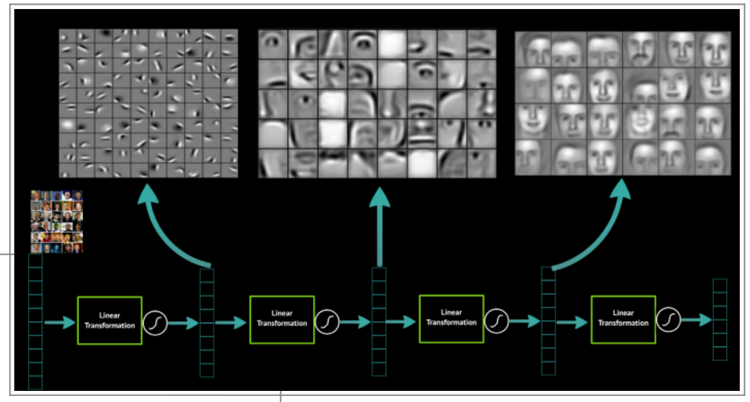
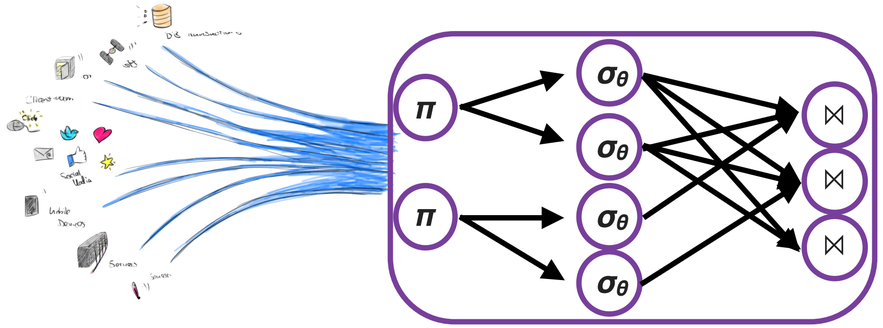


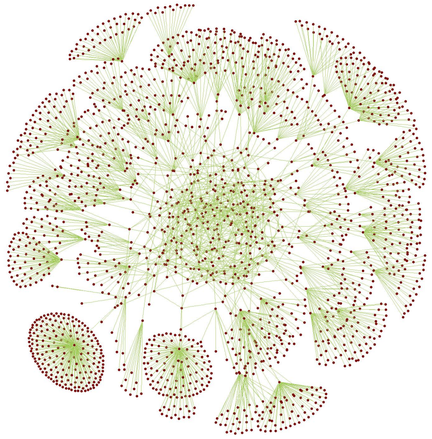
Tensor Programming



Feature Learning



Relational Data Streams



Dynamic
Graphs

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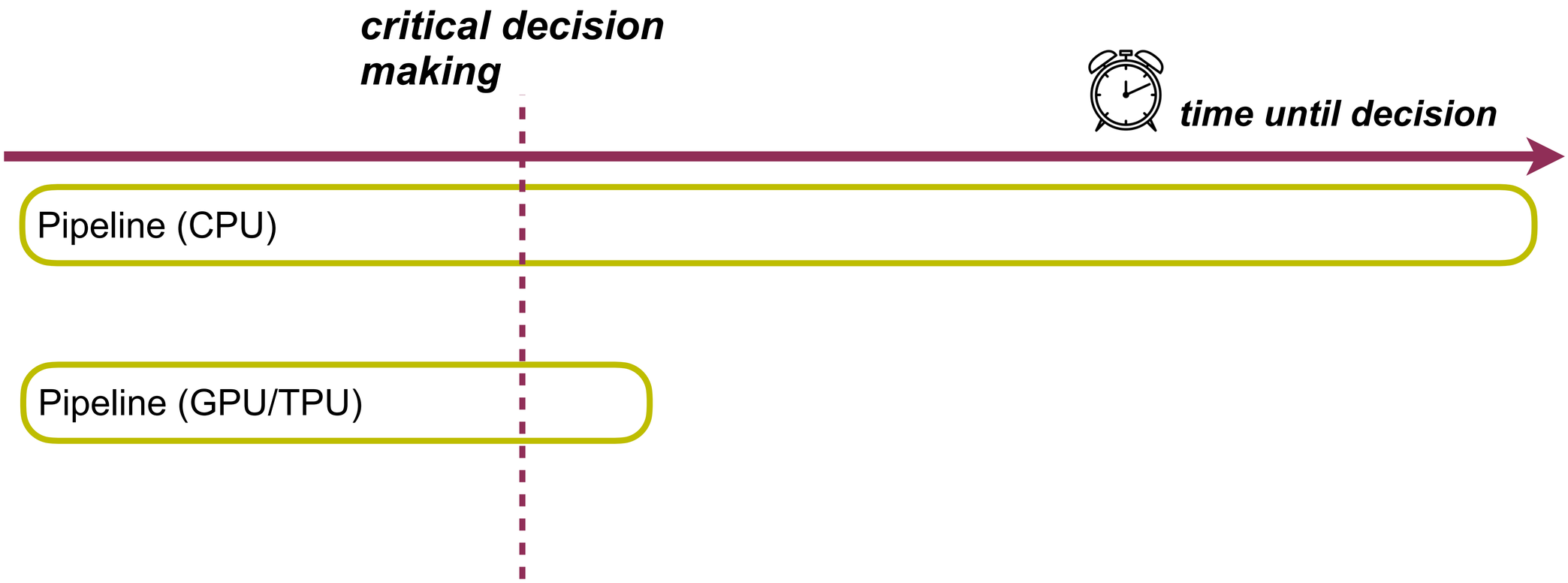
Hardware Acceleration: Important but Not Enough



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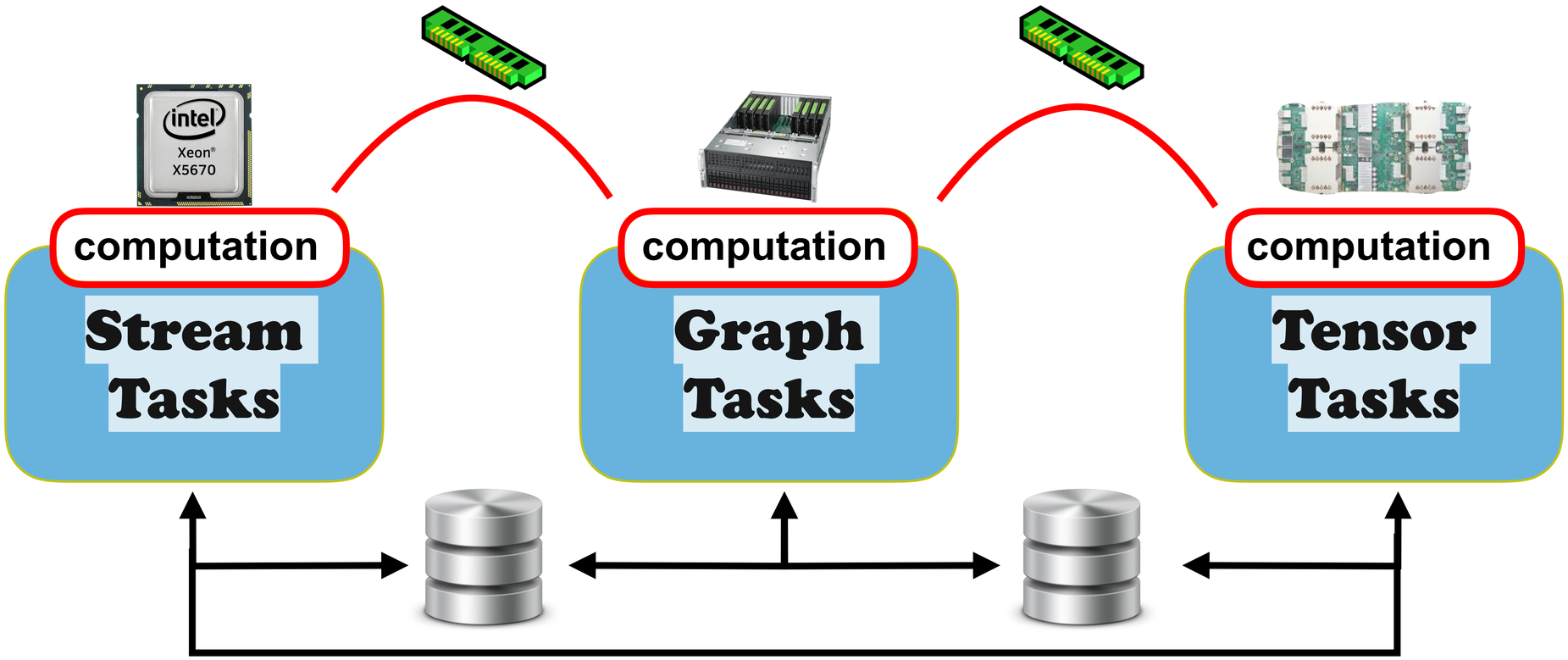
Cross-Platform Computation is Inefficient

- No computation sharing optimisations



- expensive data exchange through disk

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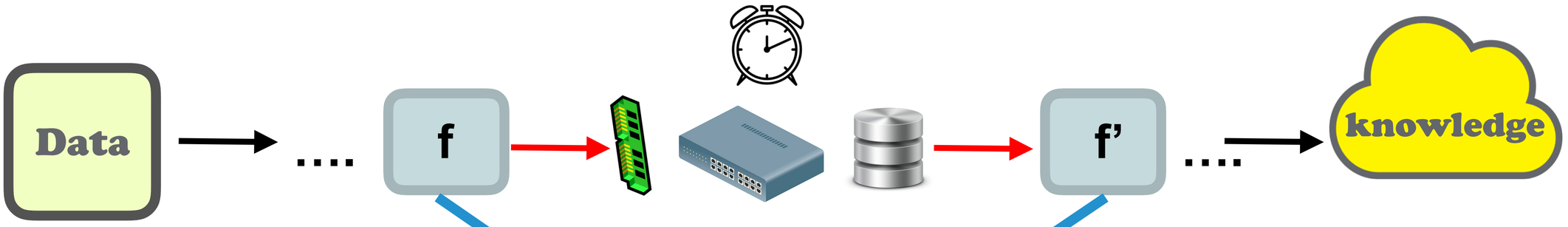
Computation Sharing



f + f'

loop fusion
vectorization
....

+less data passes
+no additional overhead

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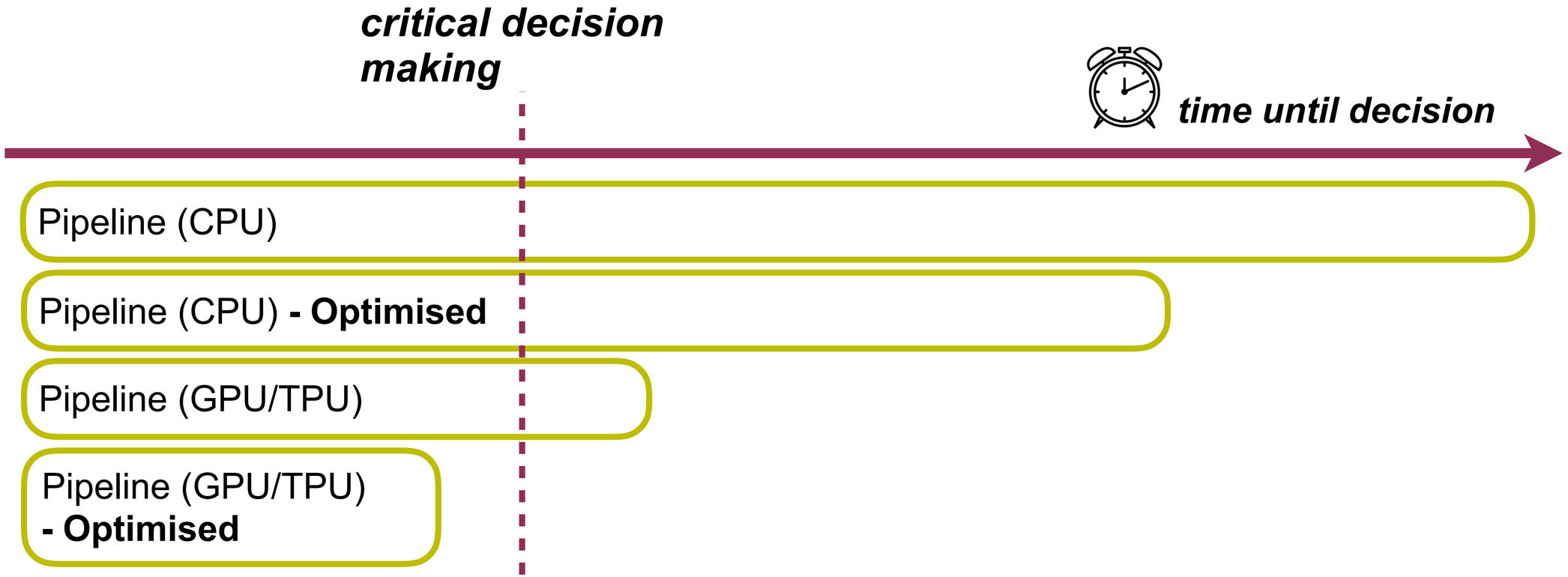
Critical Decision Making demands **Efficiency**



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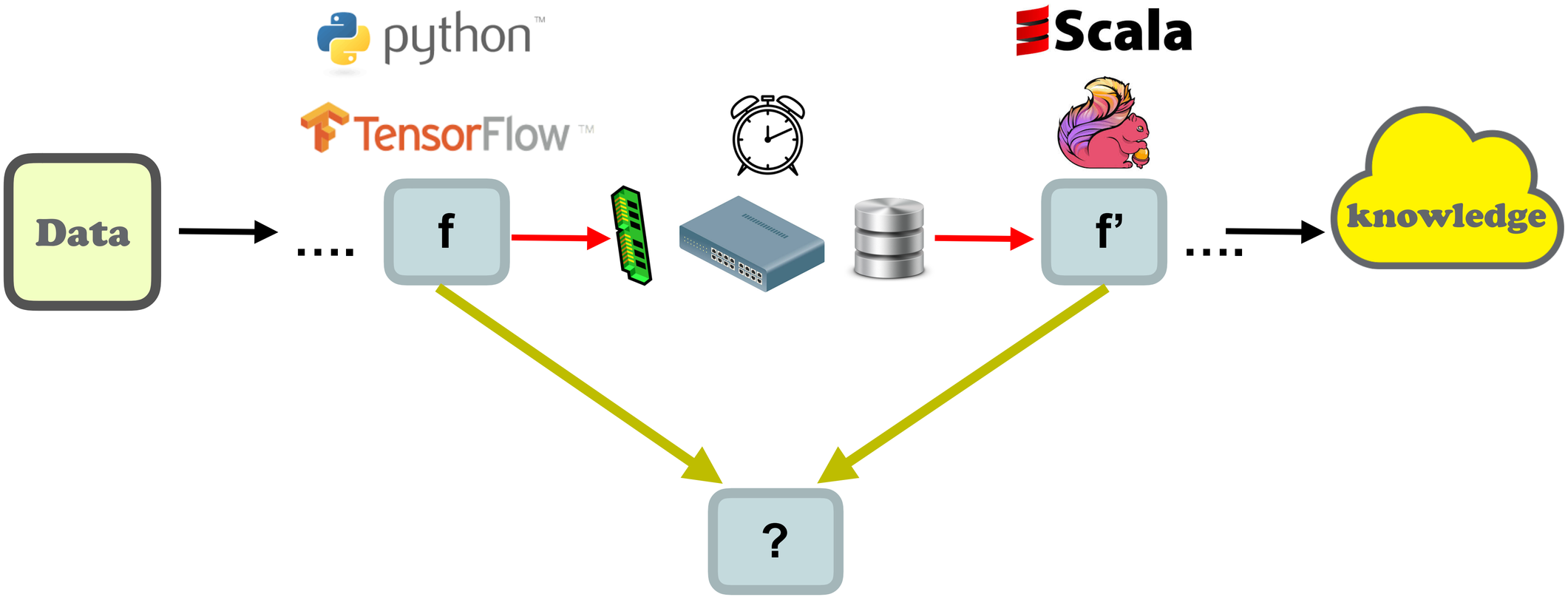
The Problem



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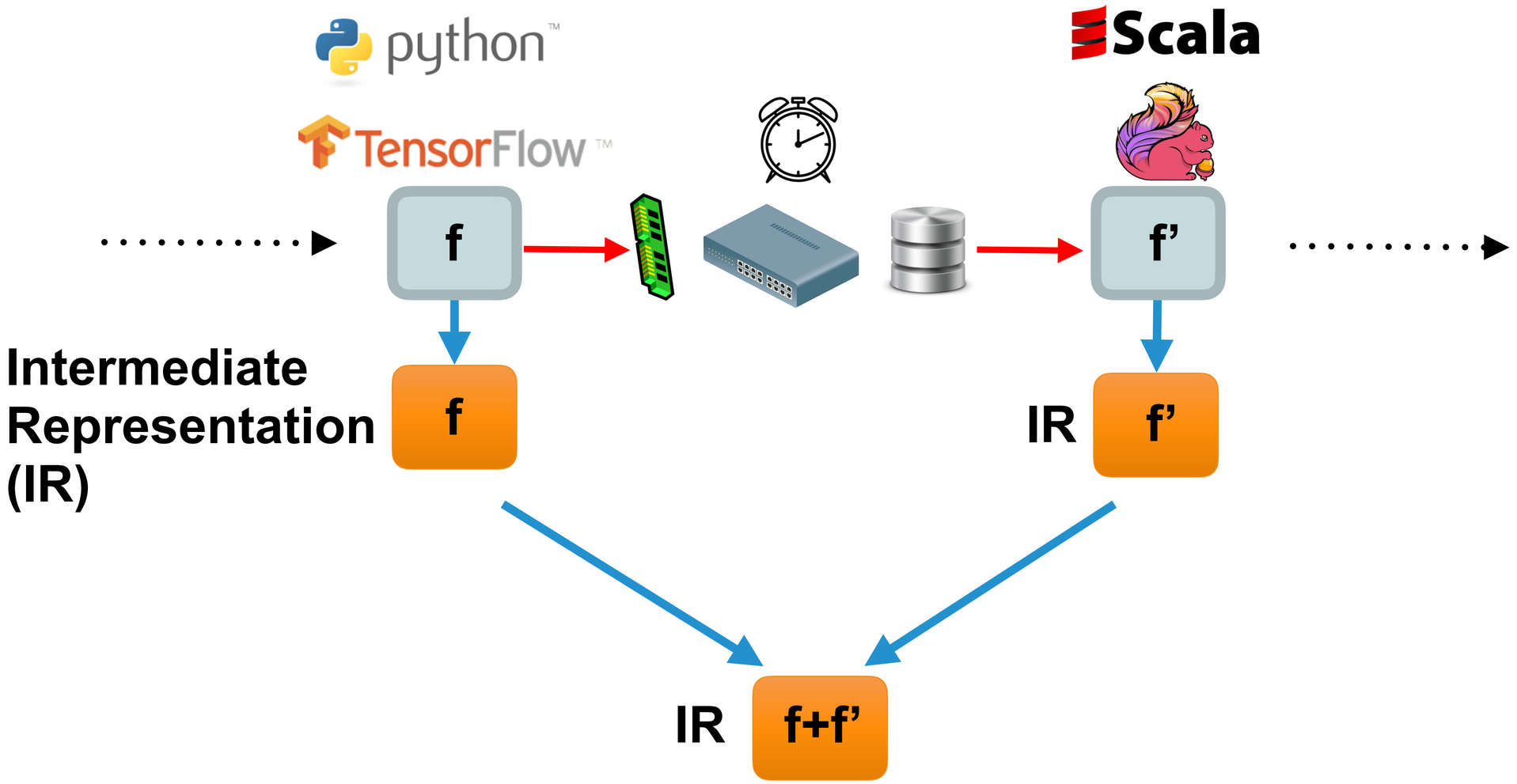
The Solution



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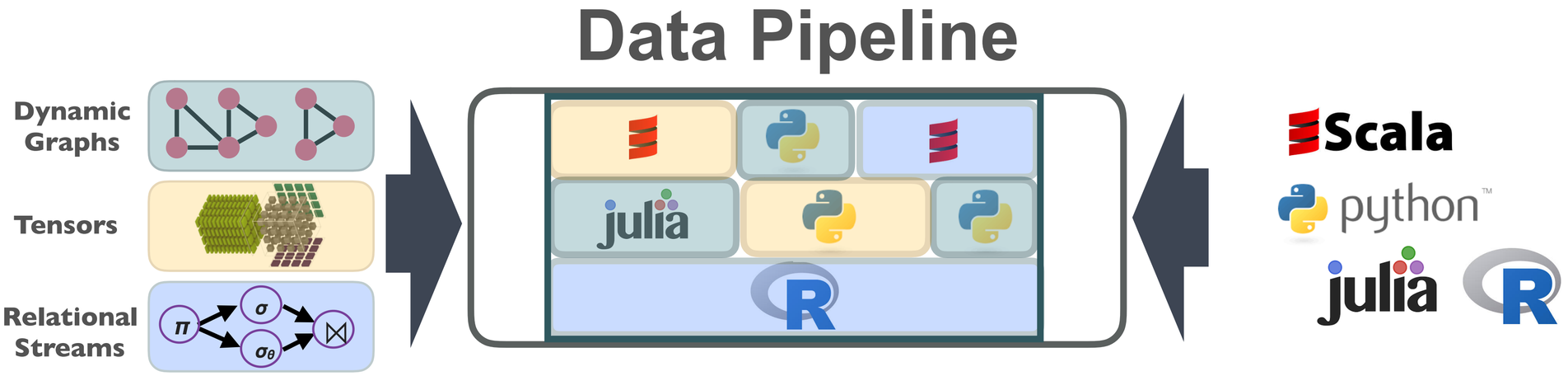
Model and Language Independence



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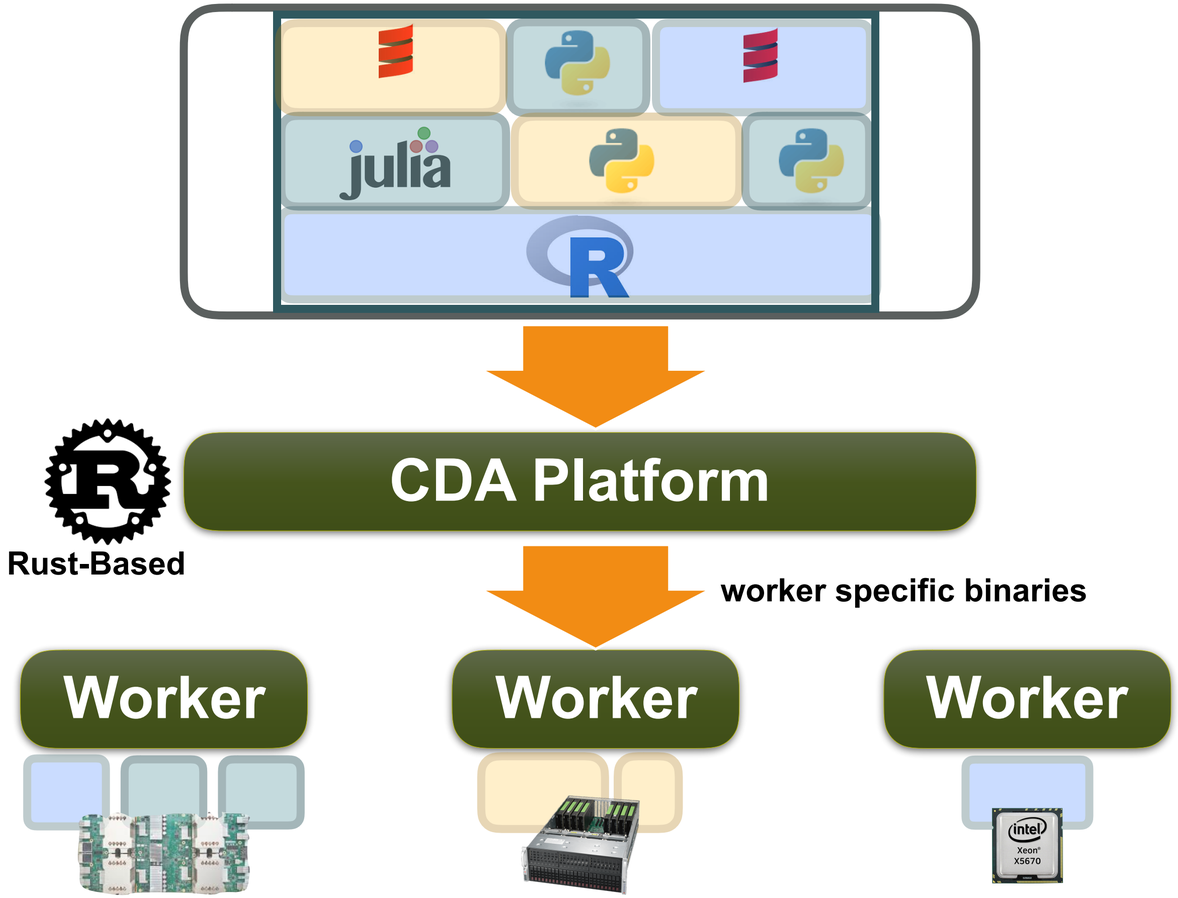
A Distributed Runtime for Heterogeneous HW



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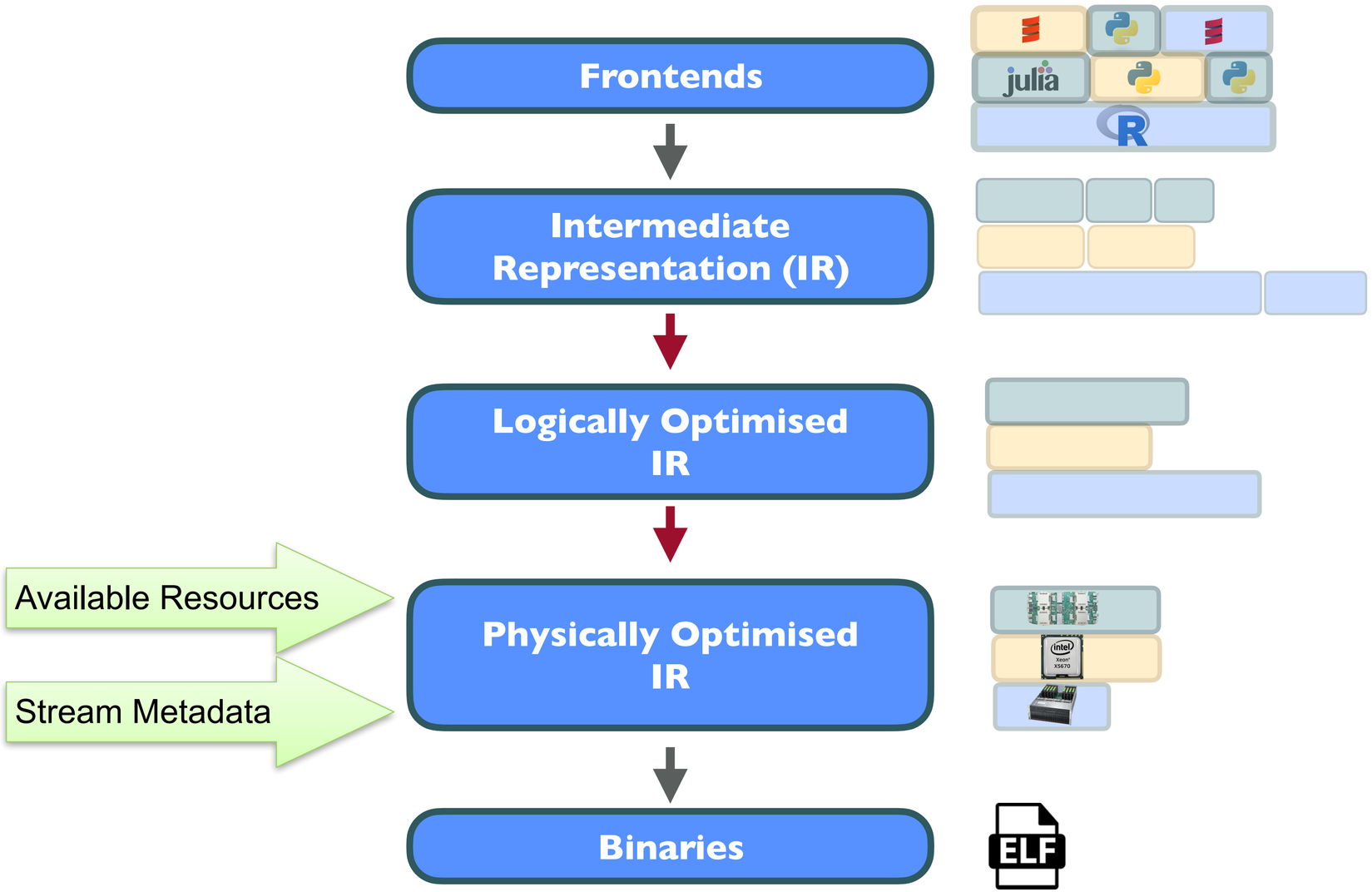
Target Architecture



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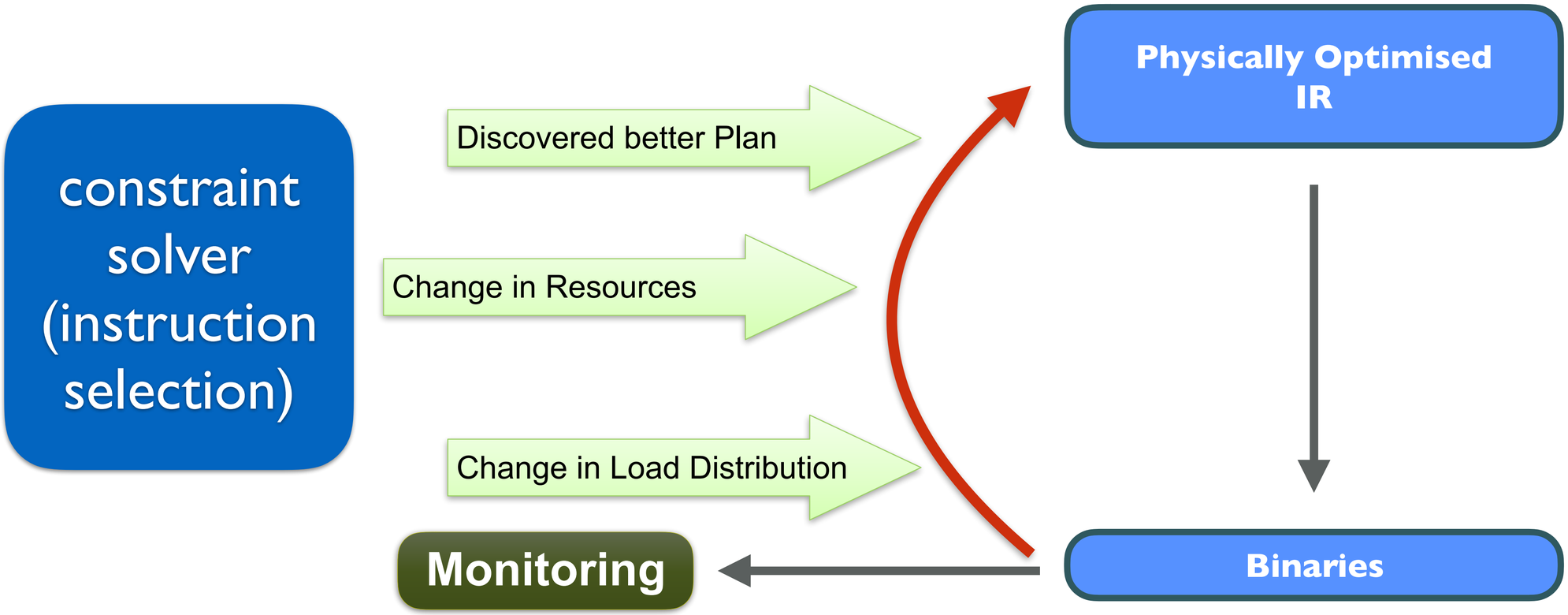
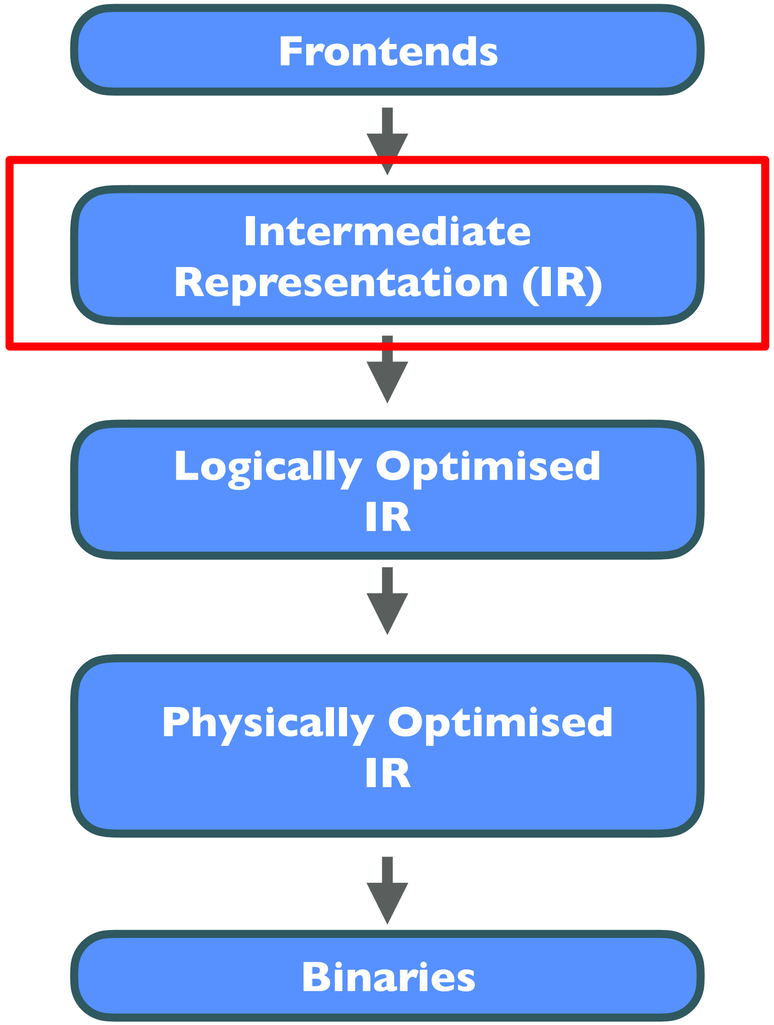
Distributed JIT Compilation





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From **Weld** to **Arc**

Extending the Weld IR for Streaming

Lars Kroll - KTH

What is Weld?

- A restrictive language for describing data transformations
- Pure expressions without side effects
- A compiler that produces LLVM IR
- Compiler leverages Weld's declarative syntax to make optimisations

Weld IR - Types

- Scalar+SIMD types
  - `bool`, `u8`...`u64`, `i8`...`i64`, `f32`, `f64`
- **Collections:** Read-only data types
  - `vec`, `dict`
- **Builders:** Write-only data types
  - `appender`, `merger`, `groupbuilder`
  - additive monads
- Structs `{...}`: more like Tuples really
  - Builders are compositional over structs
  - I.e. structs of builders are also builders

No read-write data types!

Weld IR - Ops

- `for` is a parallel loop over a collection (or iterator) and into a builder
- `merge` consumes a builder and a value and produces a new builder with the value merged in (according to the builder's semantics)
- `result` turns a builder into the corresponding type, i.e.
  - `appender[i32]` into `vec[i32]`
  - `merger[i32,+]` into `i32` (sum)
  - In Weld you may only call `result` on a builder once and it consumes the builder (*linear type*)
- `if`, `lookup`, math functions, binary ops, casts, c-udfs, etc.

KTH VETENSKAP OCH KONST
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Weld Compilation

- Online (~JIT) compilation
- Quick and easy *type inference* to support dynamically typed front-ends (e.g., Python)
- Monadic properties allow automatic *parallelisation* and *vectorisation*
- Declarative style allows data access optimisations, such as *loop fusion* and *filter reordering*

Weld Example

Scala

```
input.map(i: Int => i + 5)
```

Weld

```
|input:vec[i32]|
 result(
  for(input,
      appender[i32],
      |app, _, i|
       merge(app, i + 5)))
```

Weld Example

Scala

```
input.map(i: Int => i + 5)
```

Weld

```
|input:vec[i32]|
 result(
  for(input:vec[i32],
      appender[i32],
      |app:appender[i32], _:i64, i:i32|
       merge(app, i + 5)))
```

Arc

- **Arc** extends **Weld** for streaming
- Observation
  - *Stream Sources* are read-only
  - *Stream Sinks* are write-only
  - Connect *Sinks* to *Sources* via *Channels*
- *Source* is a **collection** `stream[T]`
- *Sink* is a **builder** `streamappender[T]`
- Calling `result` on a *Sink* returns a *Source* and creates a *Channel* between them

Arc Example I

Scala

```
input.map(i: Int => i + 5)
```

Arc

```
|source:stream[i32], sink: streamappender[i32]|
 for(source,
    sink,
    |out, i|
     merge(out, i + 5))
```

Arc Example 2

Scala

```
input.filter(i: Int => i > 5)
```

Arc

```
|source:stream[i32], sink: streamappender[i32]|
 for(source,
     sink,
     |out, i|
      if (i > 5, merge(out, i), out))
```

Arc Example 3

Scala

```
val mapped = input.map(i: Int => i + 5)
mapped.filter(i: Int => i % 2 == 0).toSink(...)
mapped.filter(i: Int => i % 2 != 0).toSink(...)
```

Arc

```
|source:stream[i32],
evenSink:streamappender[i32],
oddSink:streamappender[i32]|
let mapped = result(for(source,
    streamappender[i32],
    |out, i| merge(out, i + 5)));
for(mapped, evenSink, |out, i|
  if (i % 2 == 0, merge(out, i), out));
for(mapped, oddSink, |out, i|
  if (i % 2 != 0, merge(out, i), out))
```

Arc Example 3

Scala

```
val mapped = input.map(i: Int => i + 5)
mapped.filter(i: Int => i % 2 == 0).toSink(...)
mapped.filter(i: Int => i % 2 != 0).toSink(...)
```

Arc

```
|source:stream[i32],
 evenSink:streamappender[i32],
 oddSink:streamappender[i32]|
 for(source,
     {evenSink,oddSink},
     |out, i|
      let j = i + 5;
      if (j % 2 == 0,
       {merge(out.$1, j),out.$2},
       {out.$1, merge(out.$2, j)}))
```

Arc Windows

- Windows are supported using higher-order builders (`windower`)
- In addition to *merge*-type and *result*-type, a `windower` also has an *aggregation*-type, which must be another builder
- Use Weld functions to
  - determine window *start* and *end* points,
  - convert the *aggregation*-type into the *result*-type
  - convert the `windower`'s *merge*-type into the aggregation-builder's *merge*-type

Arc Compilation

- Ahead-of-time compilation
- Target long-running jobs (allow costly optimisations)
- Constraint-based type-inference solver
- Compile to a deployment graph IR (and from there to Rust)
- Leave pure Weld expressions to the Weld compiler
- Declarative style allows data *flow* optimisations, such as *operator fusion* and *filter reordering*