The Escape From Flatland

🐛⚗️ Building the Languages of the Future, Today 🔮🦋

Language is an instrument
of human reason, and ***not merely a medium***
for the expression of thought

– George Boole

Daring ideas are like
chess pieces moved forward.
They may be ***beaten***,
but they may ***start a winning game.***

– Goethe

Brooklyn Zelenka

@expede

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- CTO at Fission (https://fission.codes)
  - Far edge apps ("post-serverless")
  - Goal: make back-ends and DevOps obsolete

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https://lu.ma/distributed-systems

Meta 🔄

Two Keynotes, Both Alike in Dignity 🎭

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Part I: Empex MTN 🇺🇸

Part II: CodeBEAM EU 🇸🇪

Meta 🔄

Growth Mindset

Meta 🔄

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We ❤️ Elixir

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It's important to think ***critically*** about our tools

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Growth requires ***dissatisfaction & inspiration***

Meta 🔄

Growth

It's imp ur tools

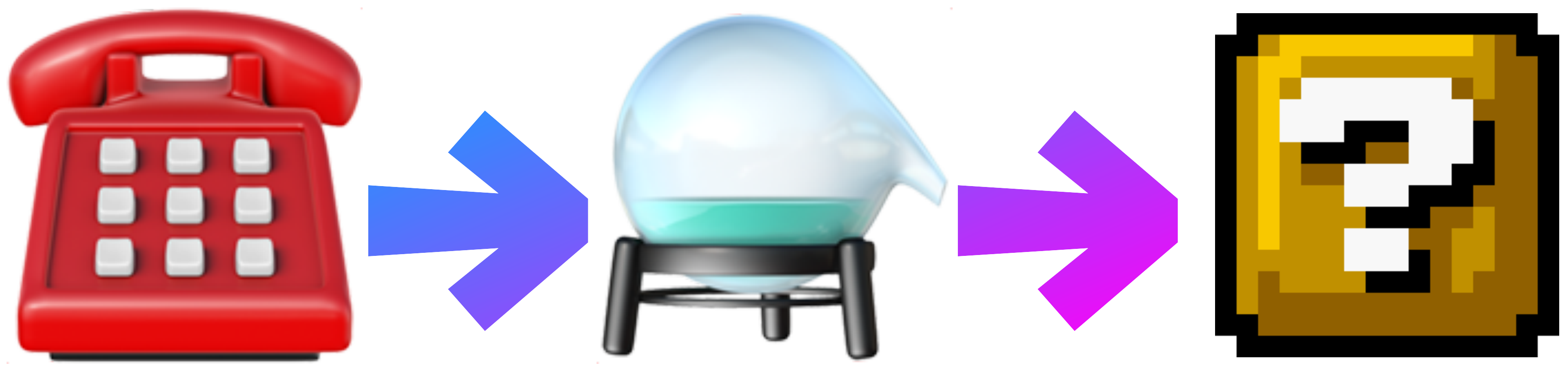
We nee *ndard*

Let *ns*

Growth r *iration*

The Children of Elixir

Manifesto



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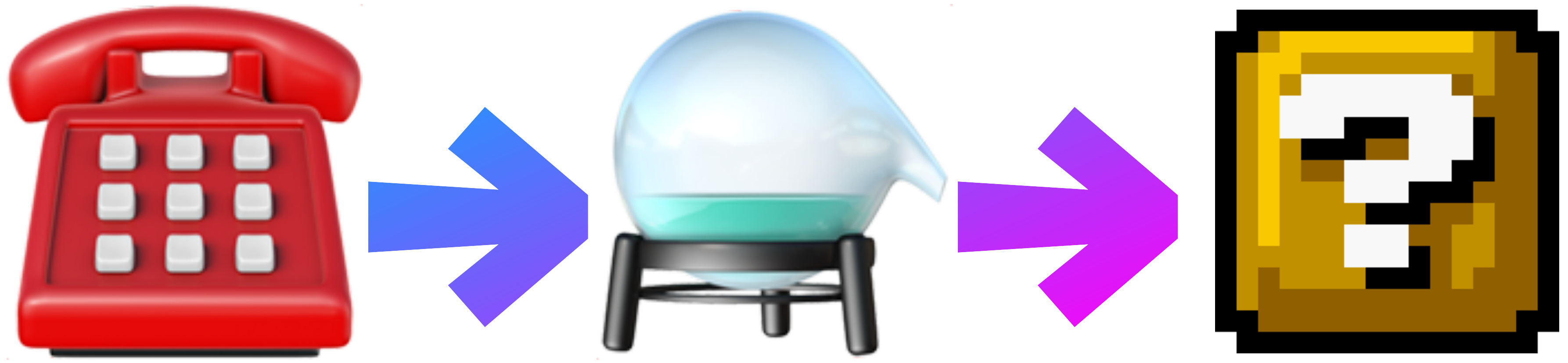

Manifesto ☎️→🫖→❓

My Obsession

Manifesto ☎️→🫧→❓

My Obsession

Manifesto ☎️→🔮→❓

My Obsession

The BEAM does ***so much right*** 👏

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Where do we go from here?

Manifesto ☎️→🔮→❓

Our Code is Too "Flat"

Manifesto ☎️→🔮→❓

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Code in 2022 is ***needlessly difficult & complex!***

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How do we ***add dimension?***

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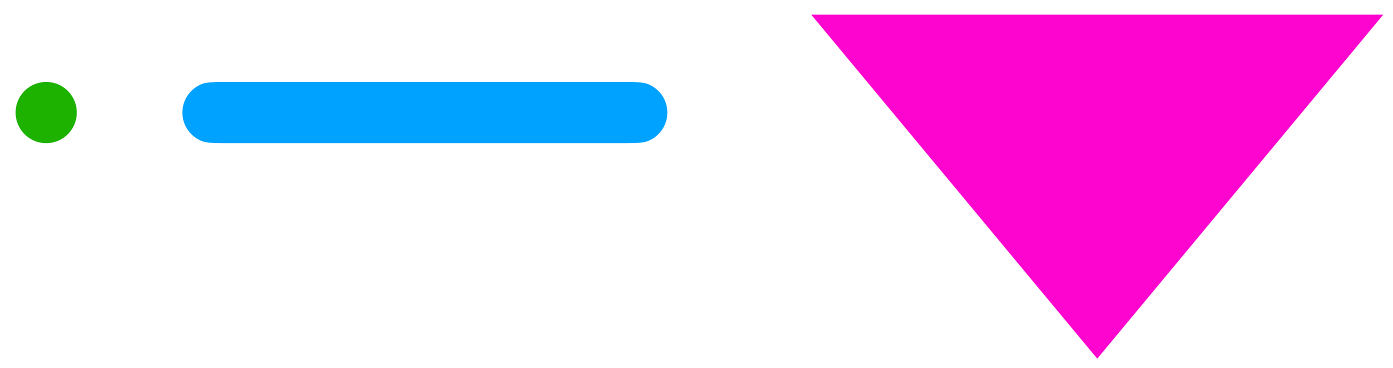

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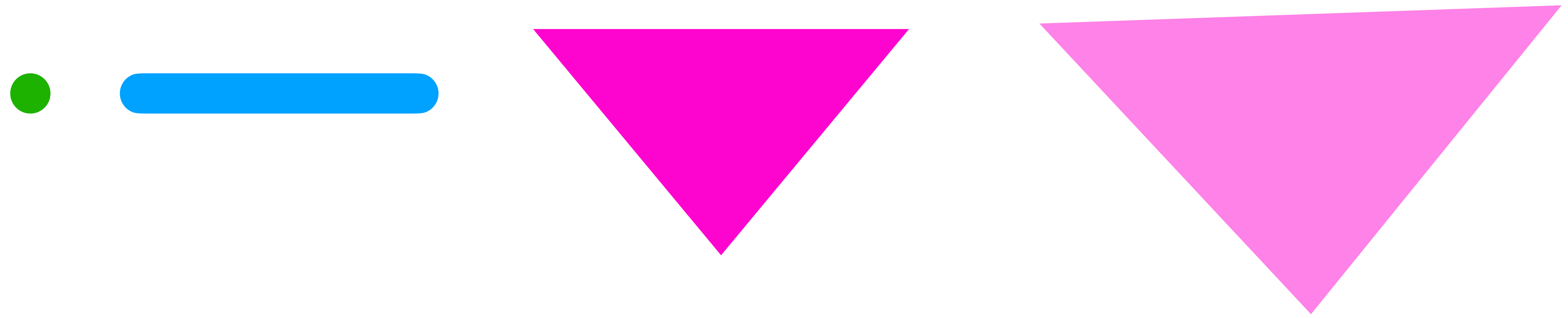

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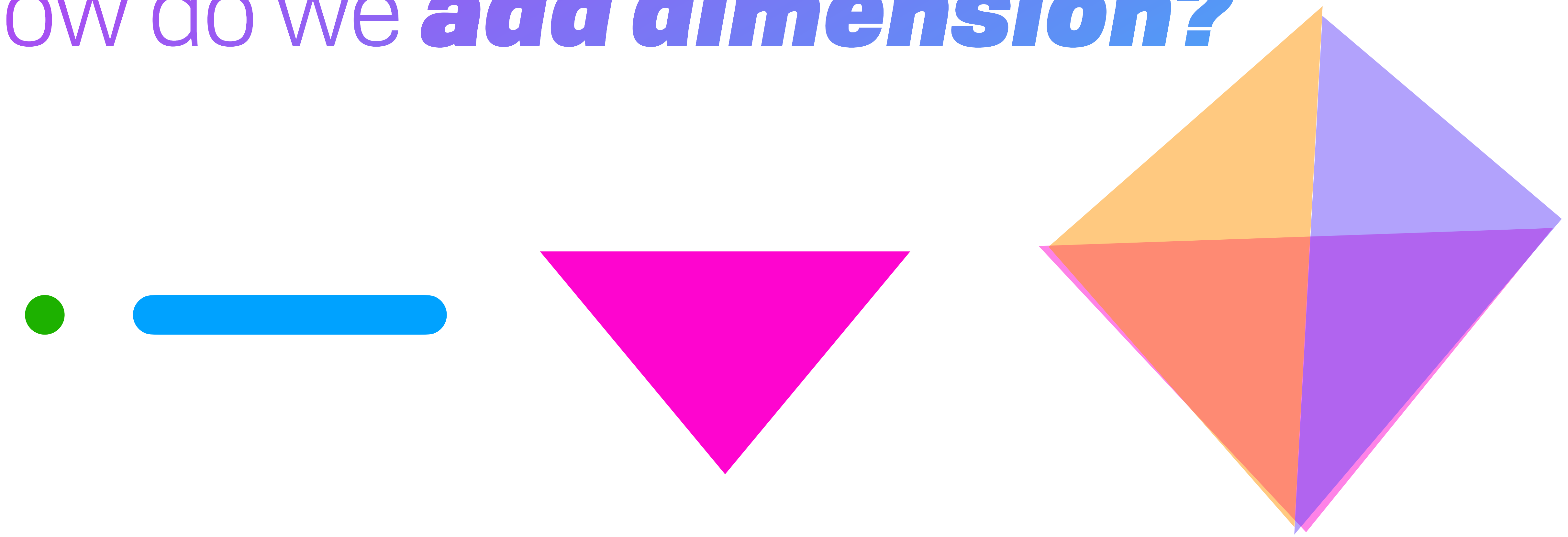

Manifesto ☎️→🔮→❓

The Pit of Success

Manifesto ☎️→🔮→❓

The Pit of Success

In stark contrast to a summit, a peak, or a journey across a desert to find victory through many trials and surprises, we want [devs] to ***simply fall into winning practices*** by using our platform and frameworks. ***To the extent that we make it easy to get into trouble we fail.***

– Rico Mariani, Microsoft Research MindSwap 2003

Manifesto ☎️→🔮→❓

Tools For Thought

Manifesto ☎️→🔮→❓

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Tools For Thought

- We have better mental tools than our ancestors
- Abstraction appears 50k-100k years ago
- Arabic numerals > roman numerals
- Metric conversions > Imperial
- 24-hours & 360-degrees have nice divisiors

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Random Walk

Image by Pradyumna Yadav

Manifesto ☎️→🔮→❓

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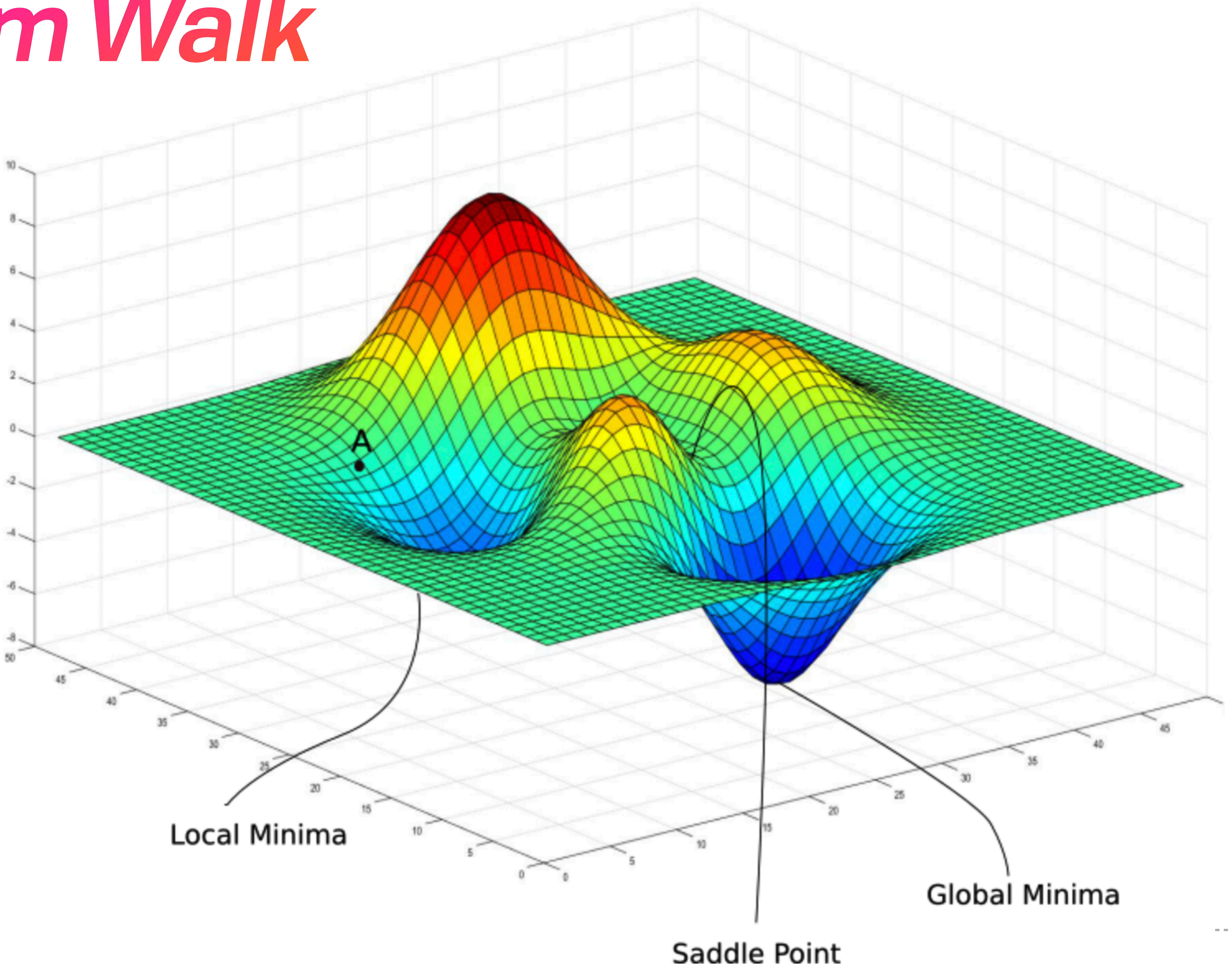

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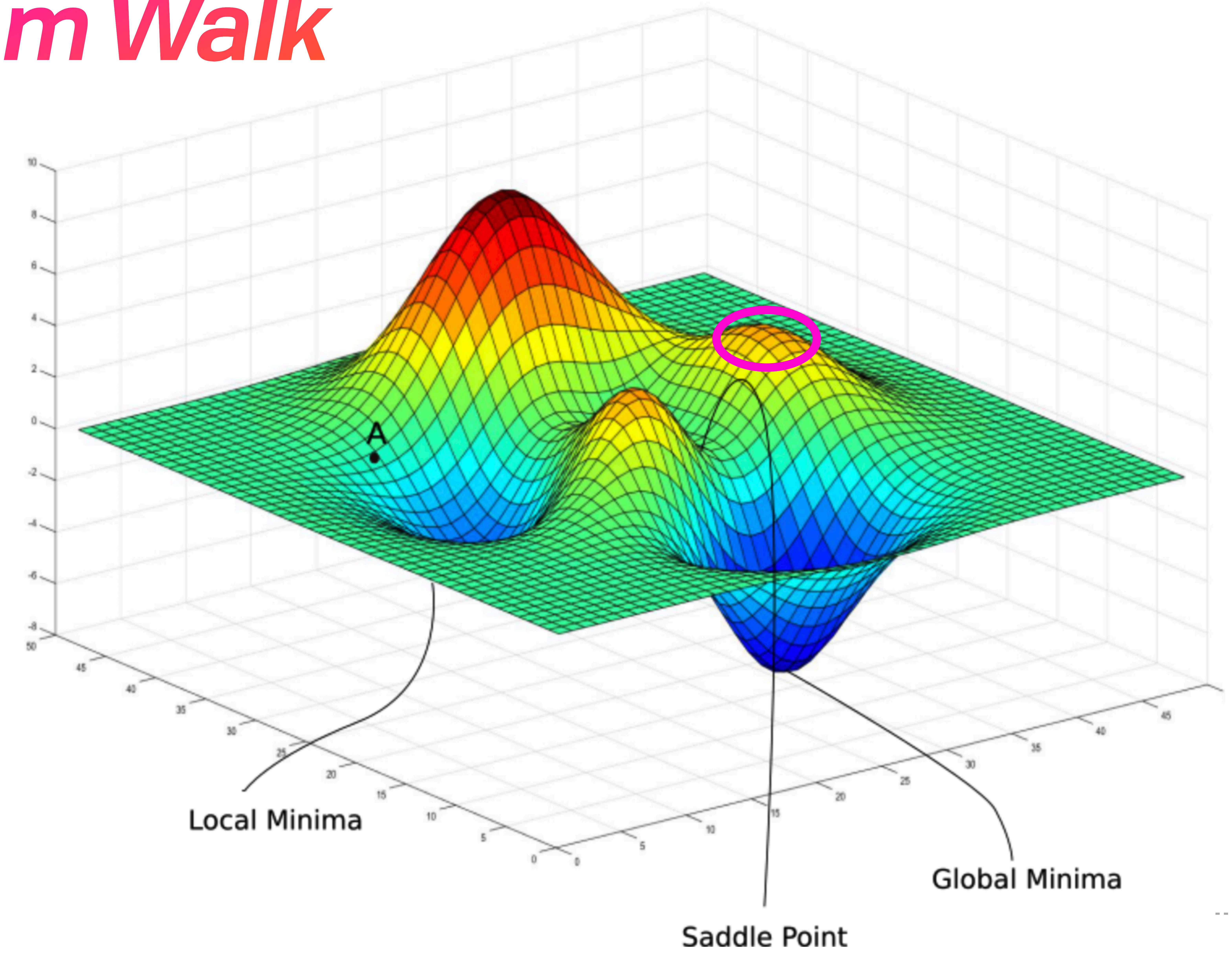

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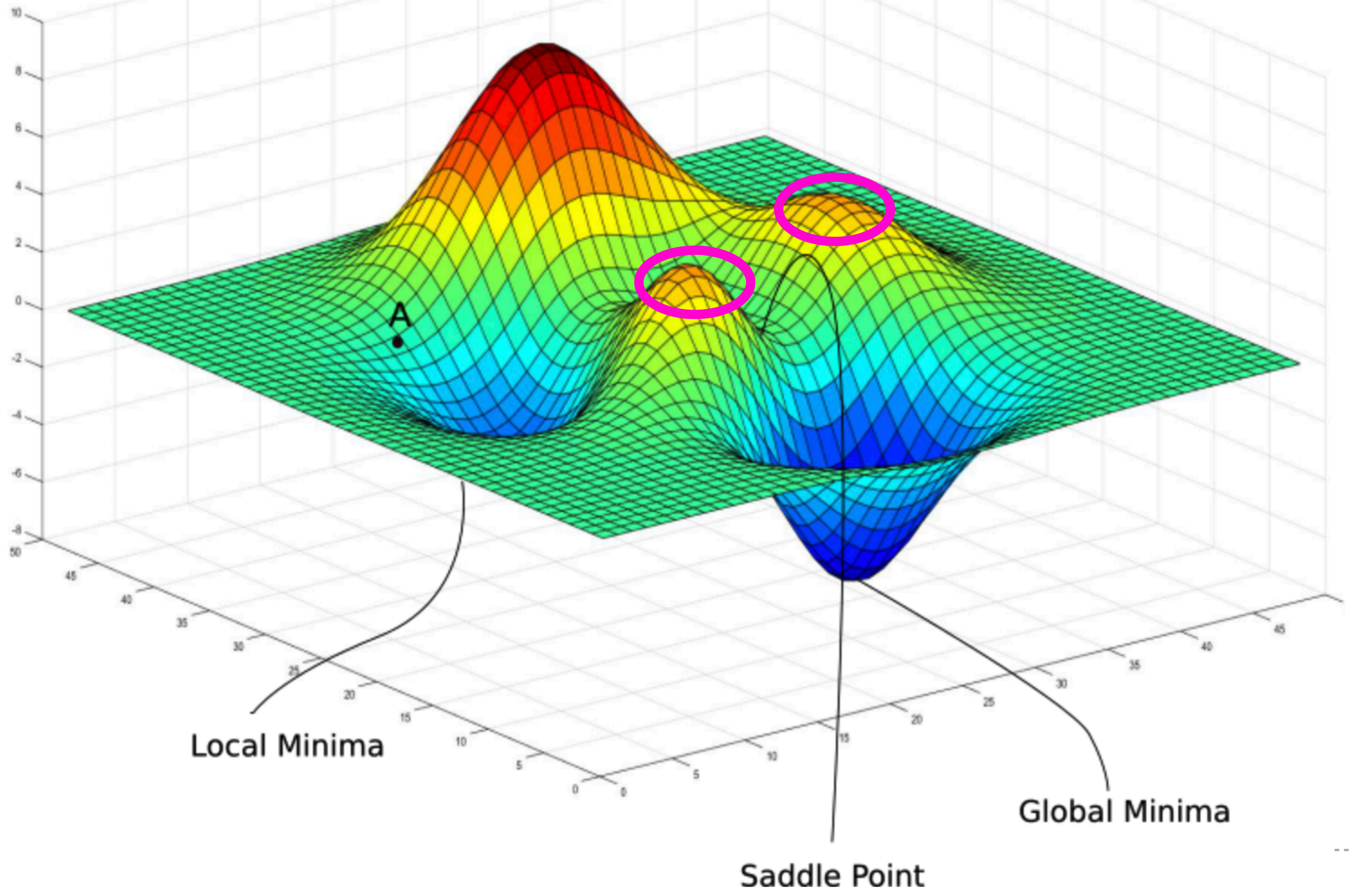

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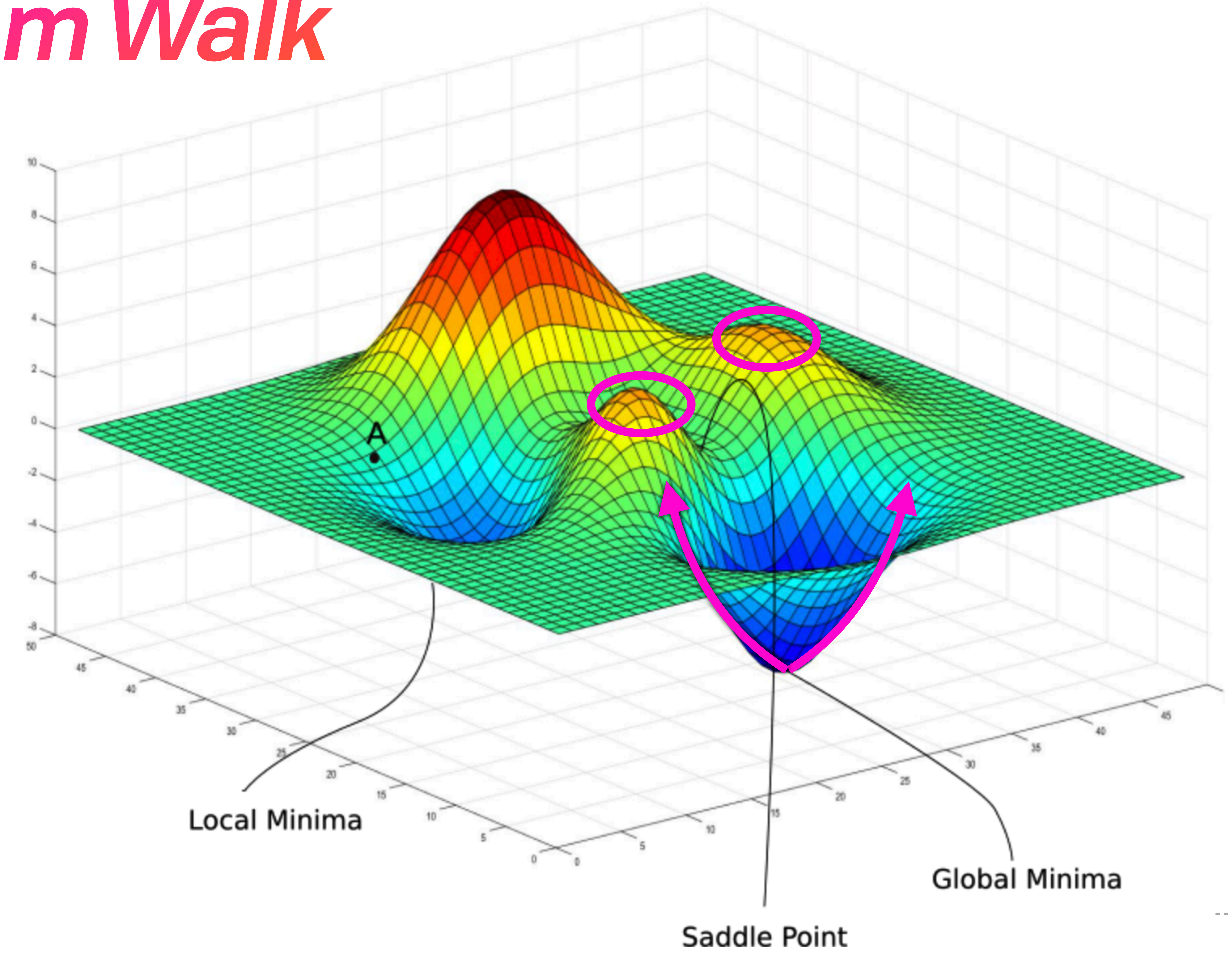

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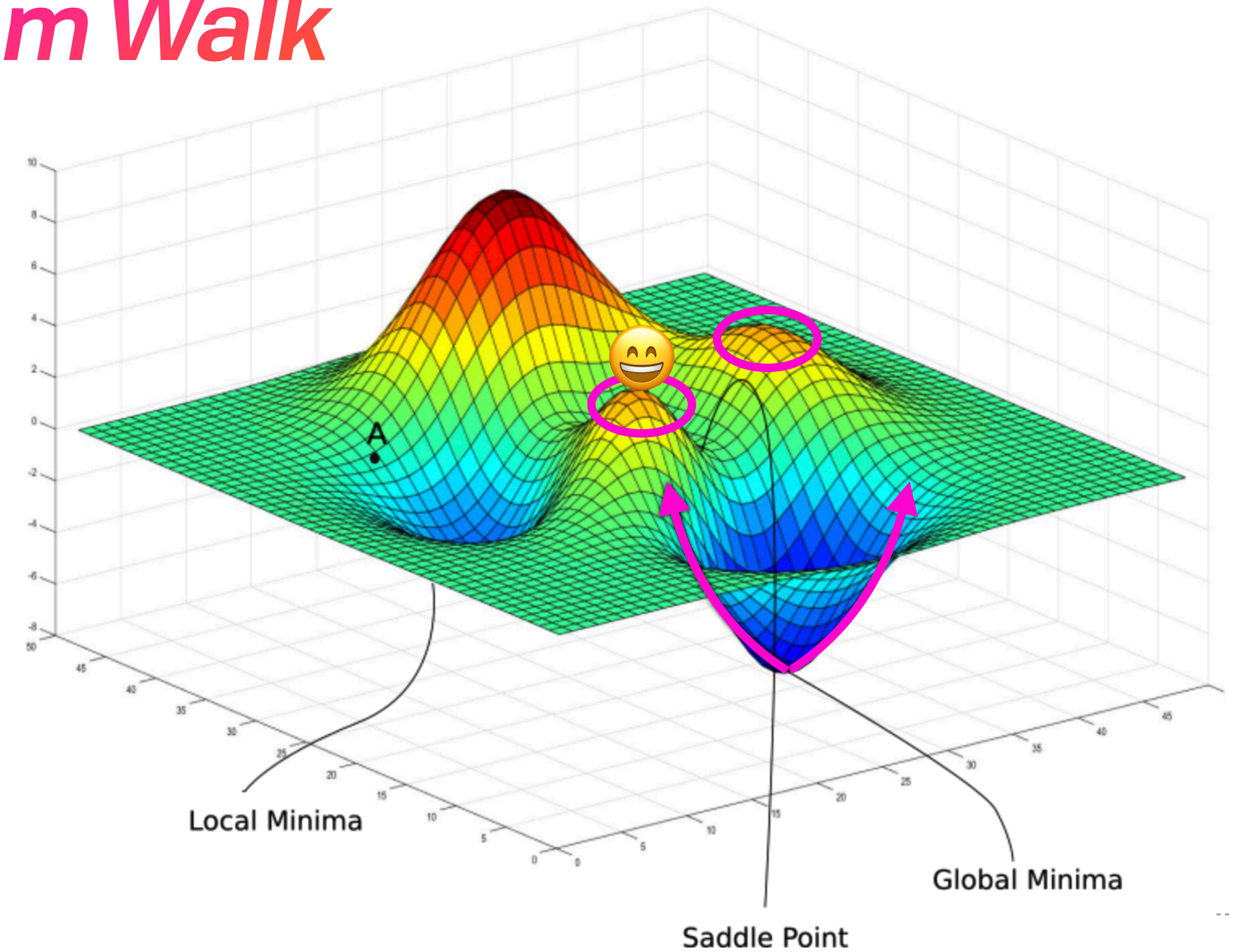

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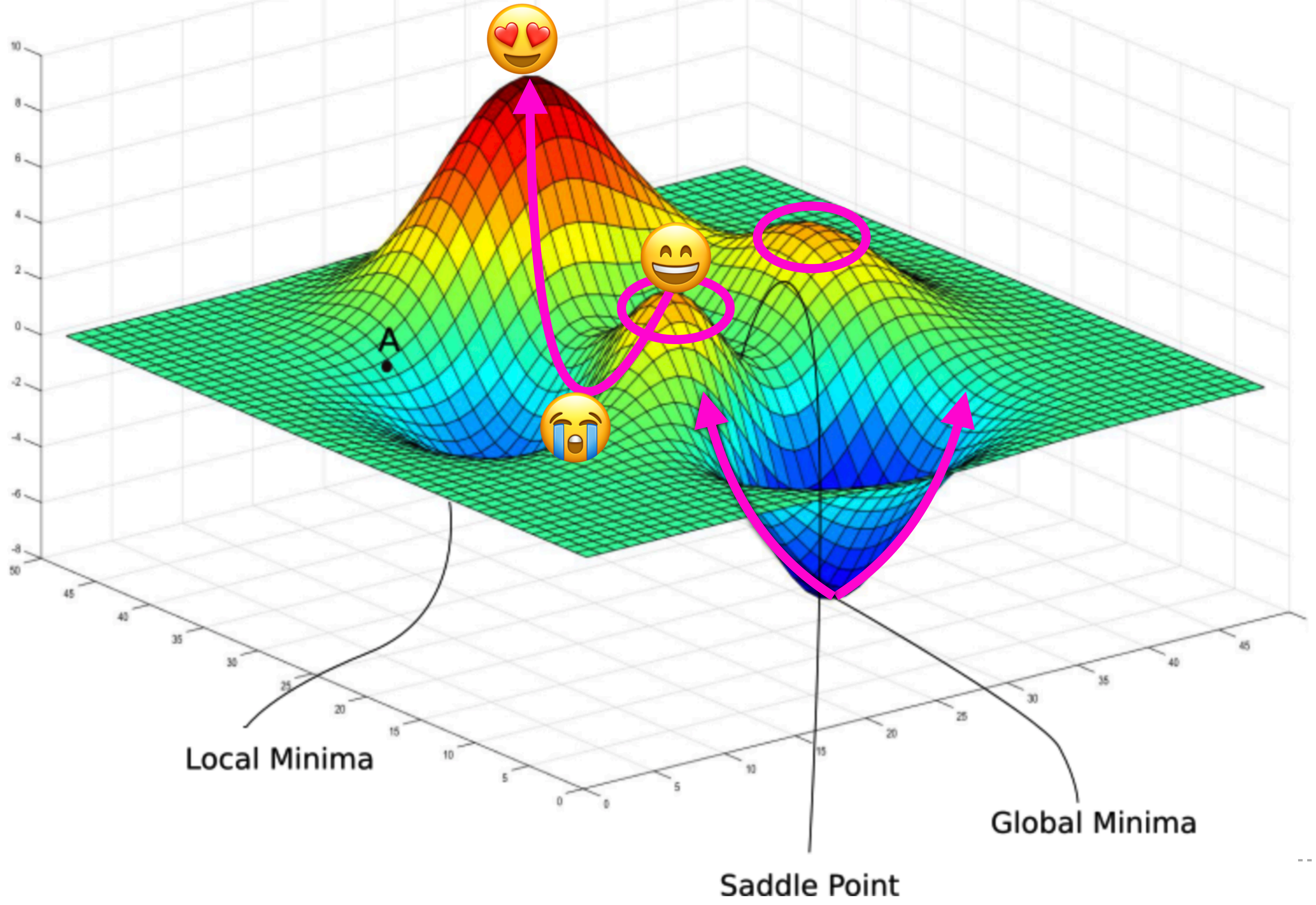

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The World Is Changing

Manifesto ☎️→⚗️→❓

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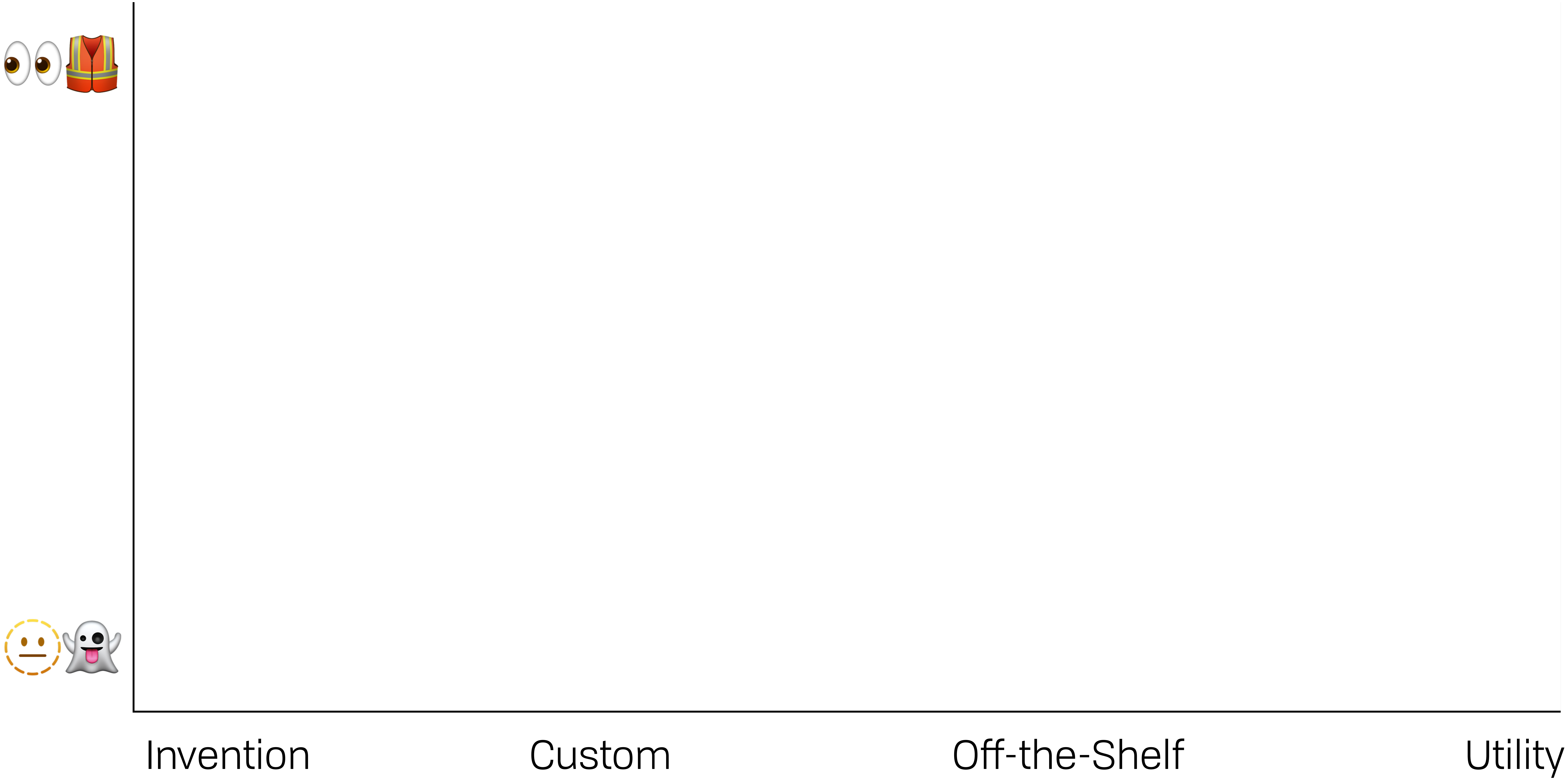

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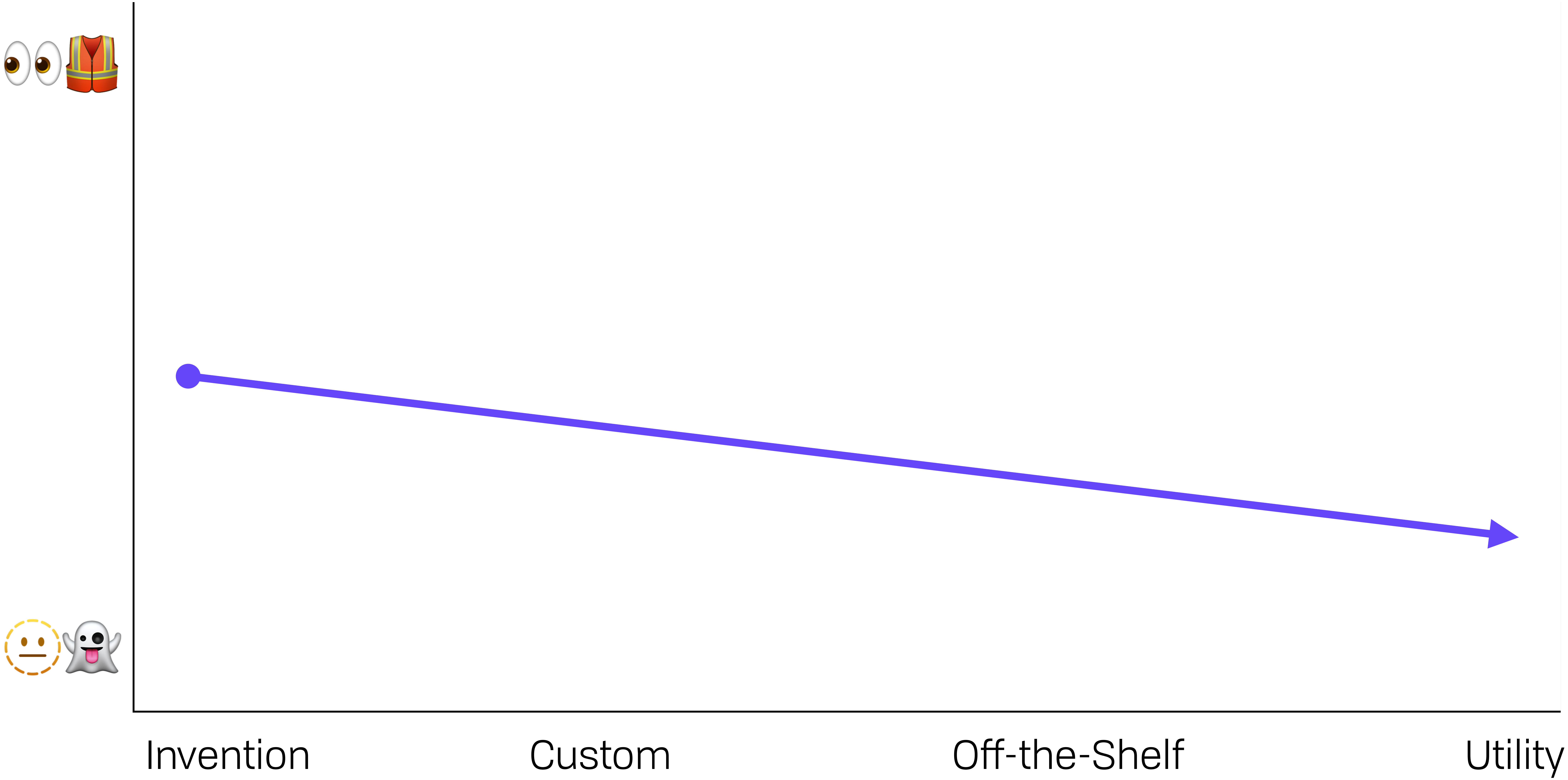

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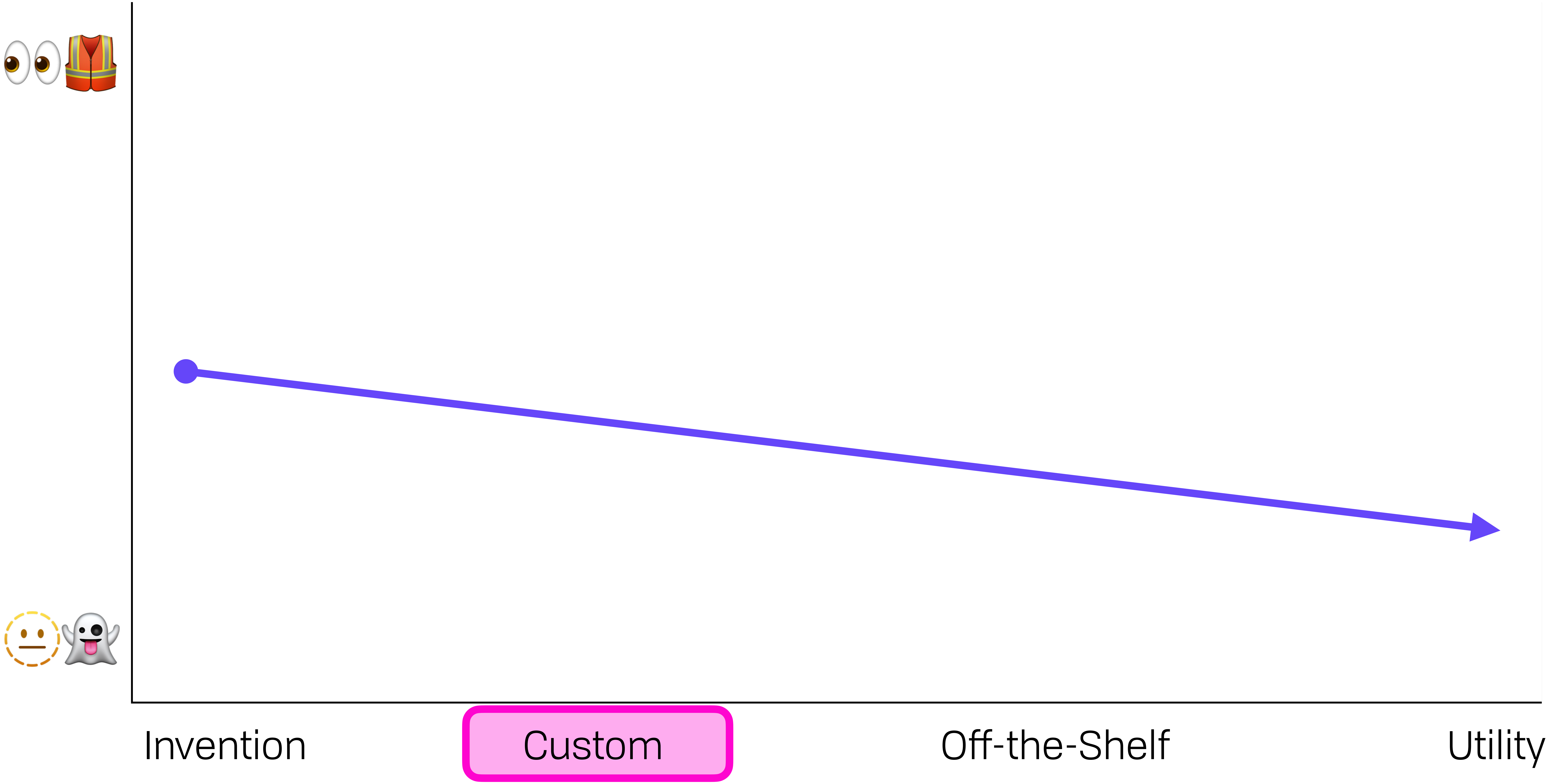

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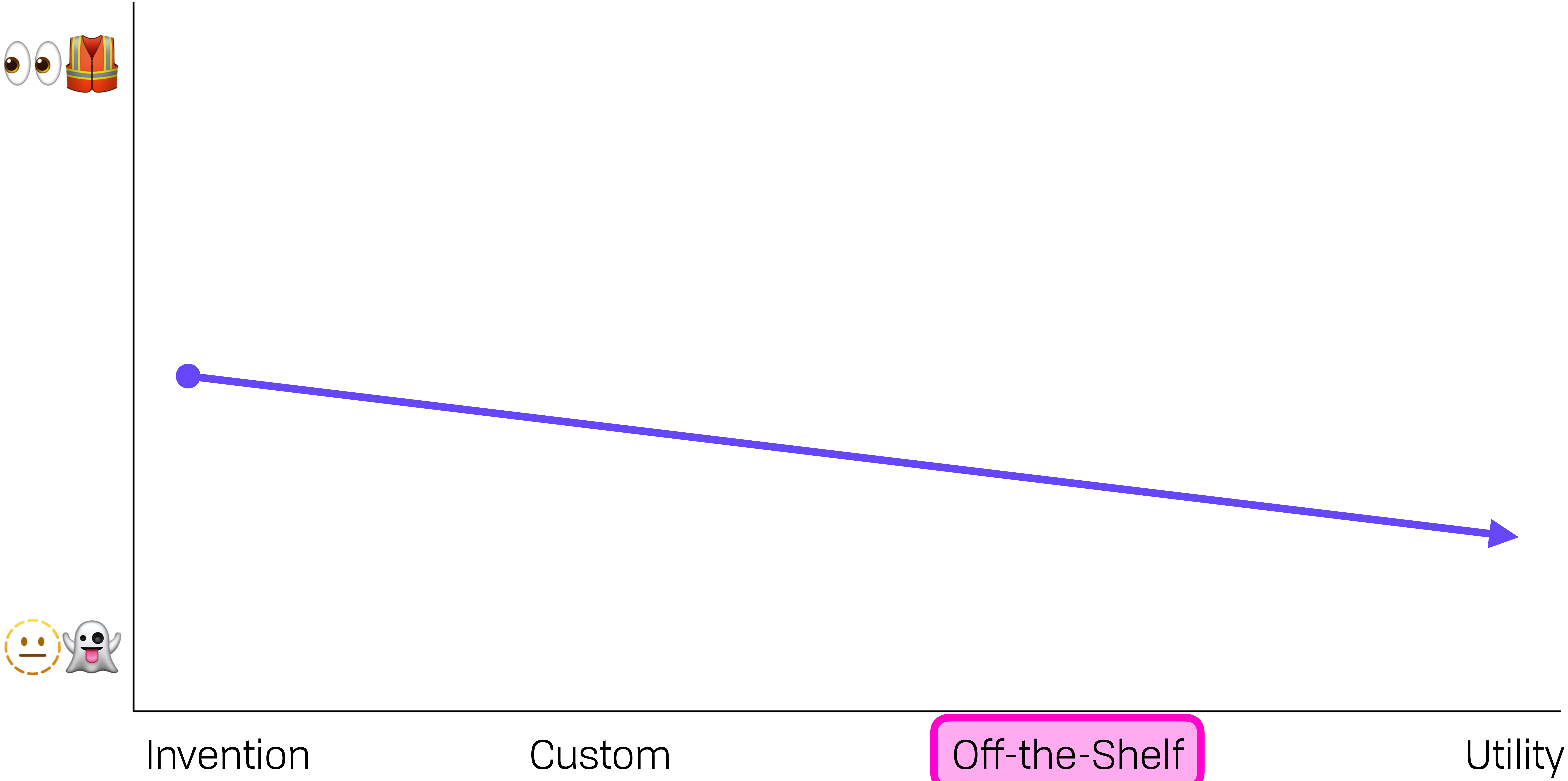

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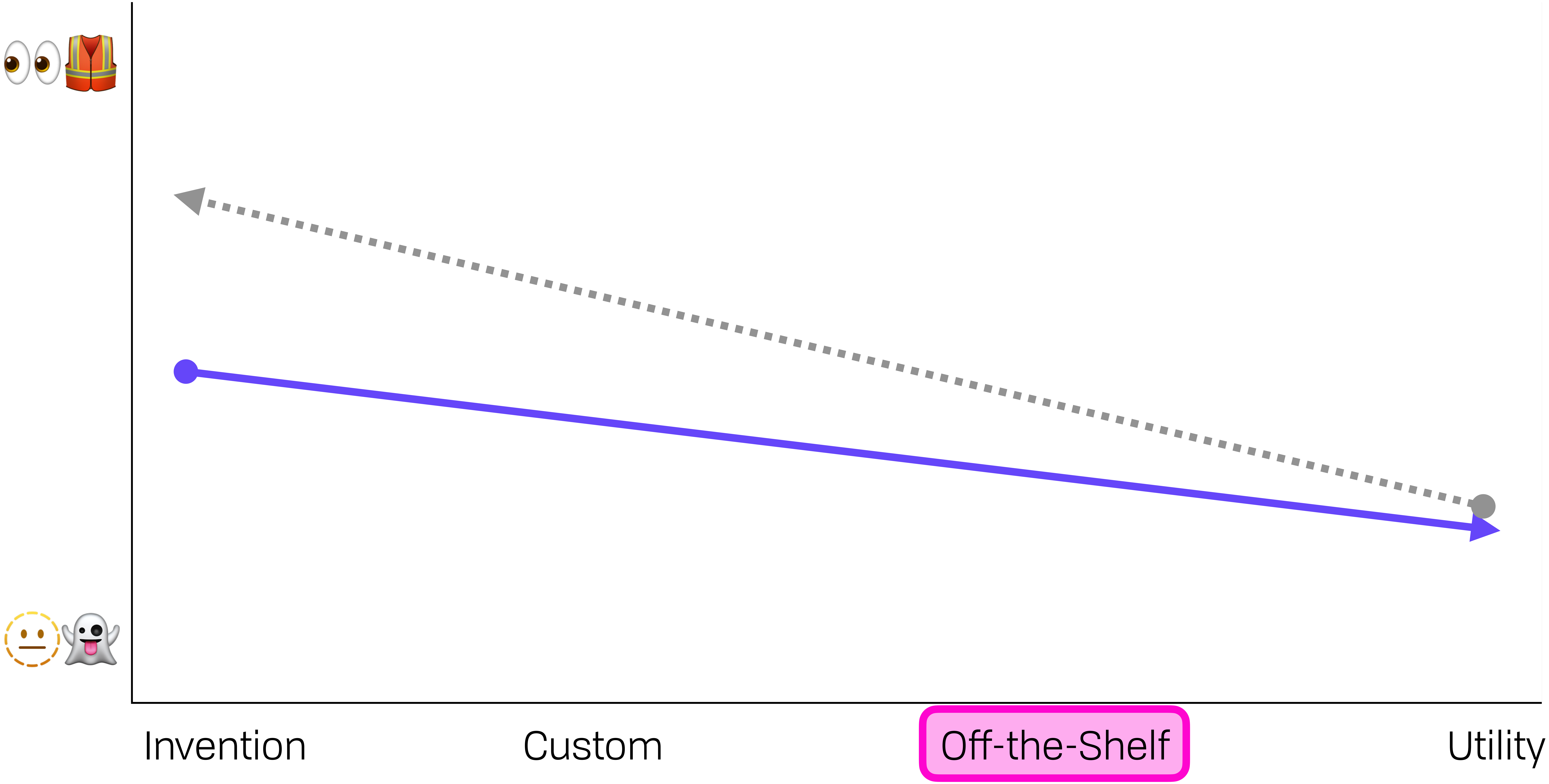

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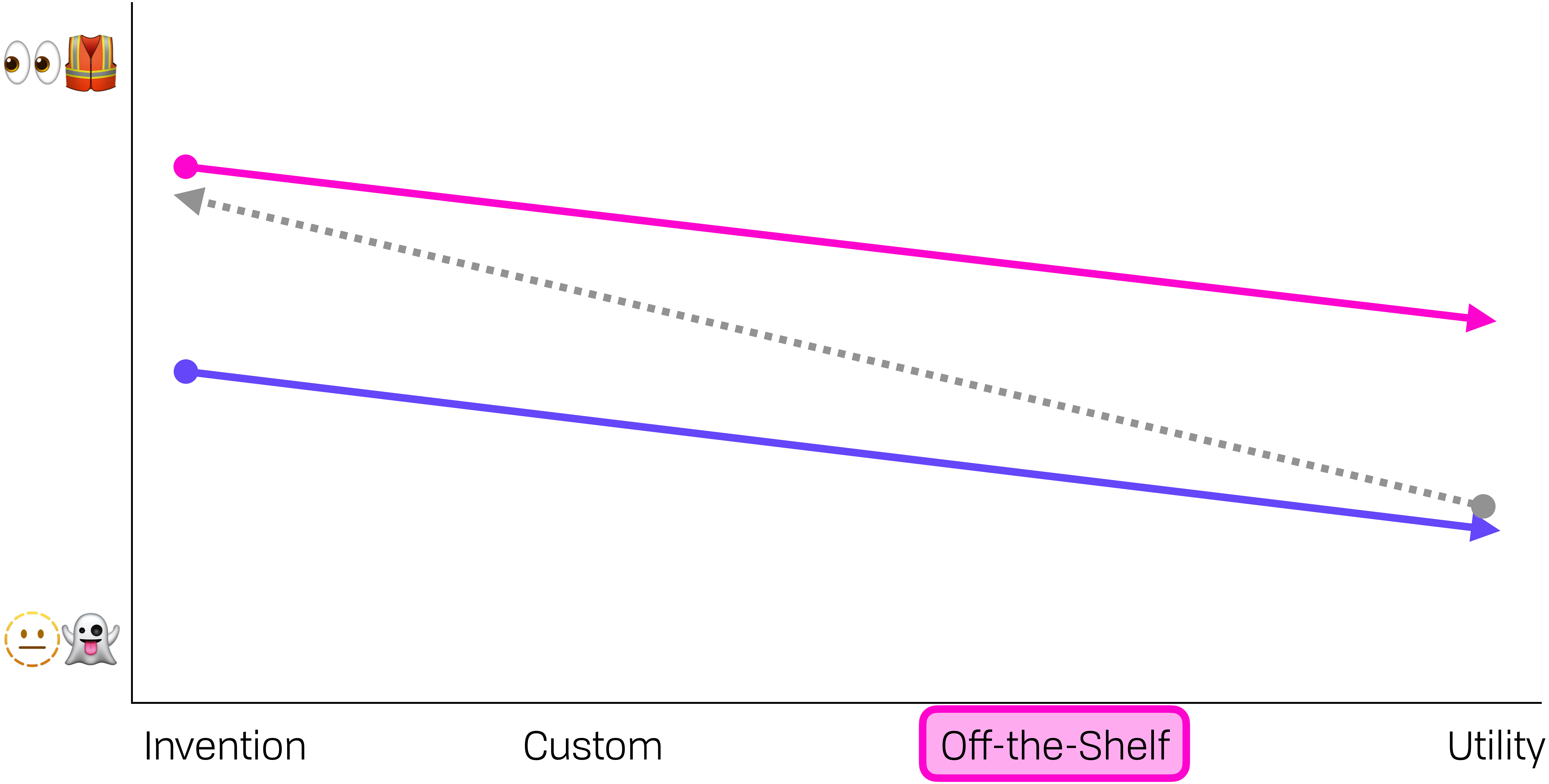

Manifesto ☎️→🔮→❓

A Cambrian Explosion of Approaches!

Manifesto ☎️→⚗️→❓

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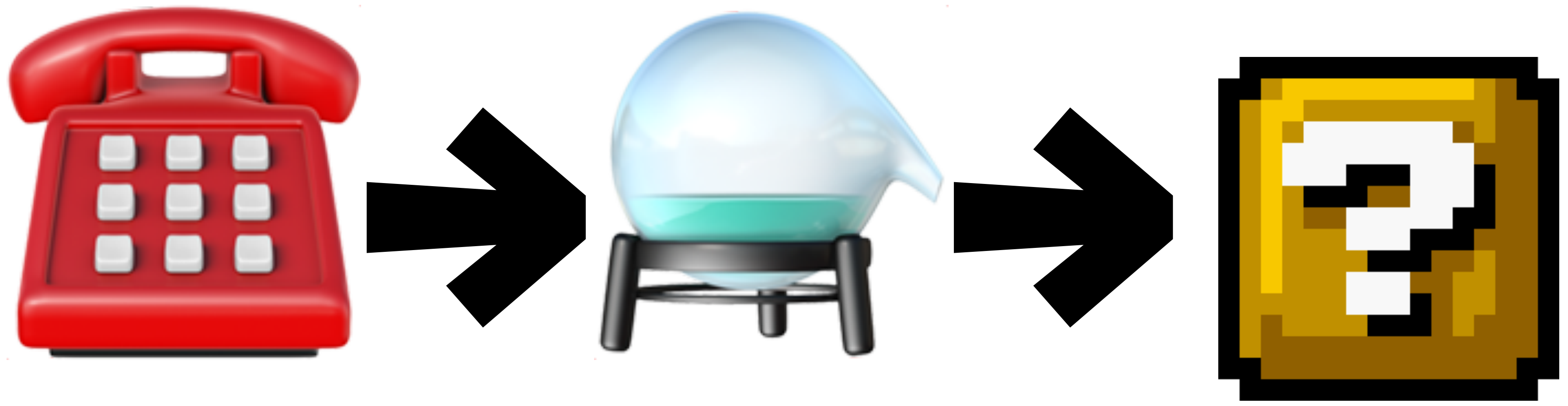
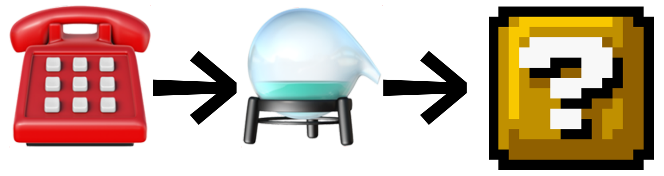


Manifesto 

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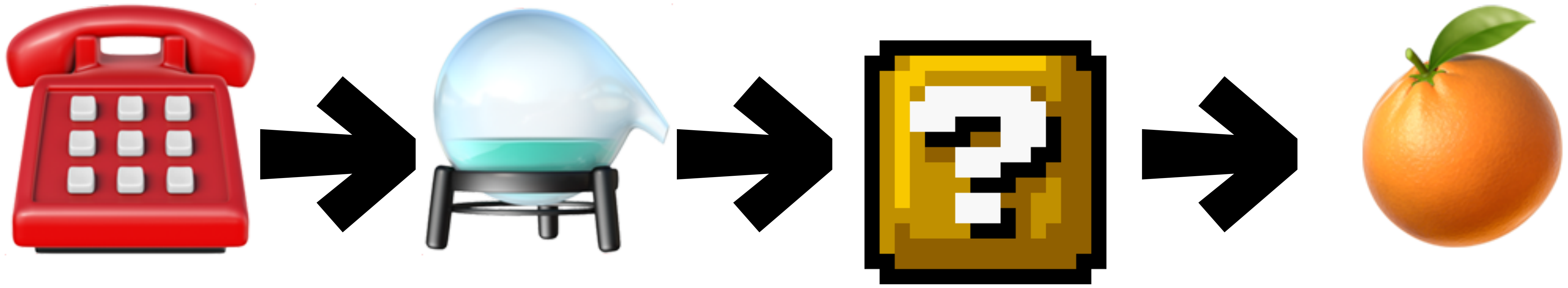

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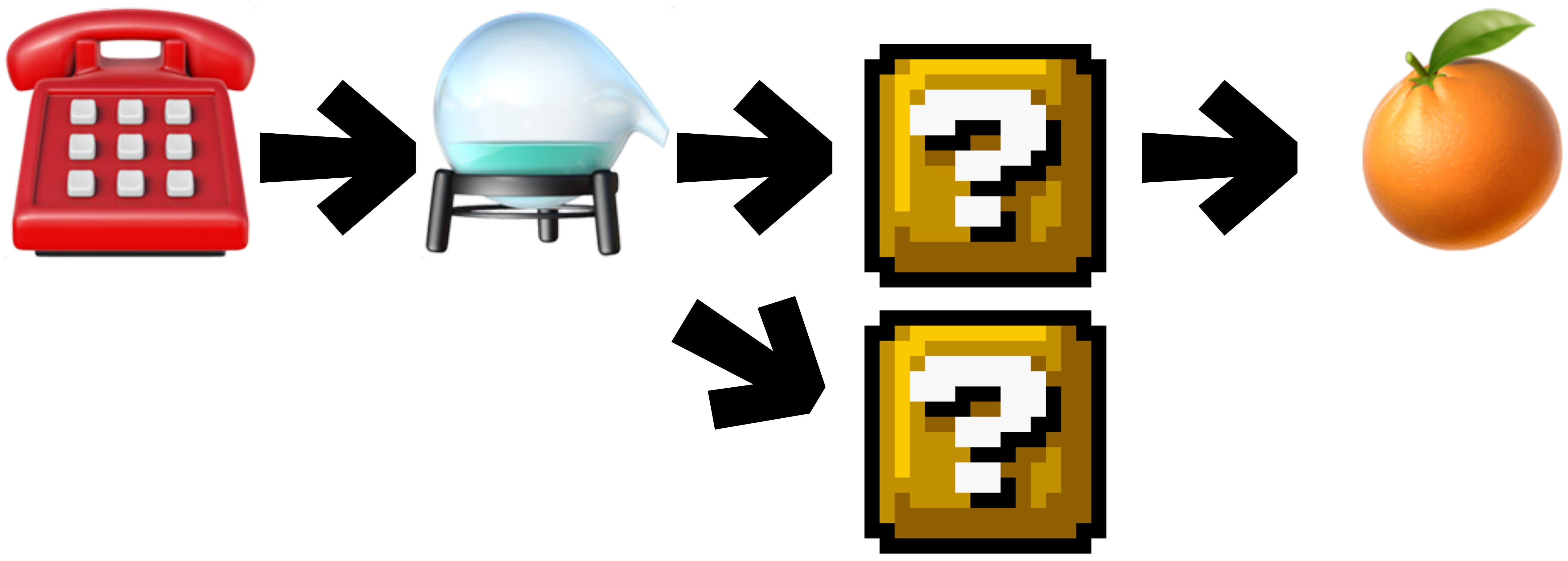

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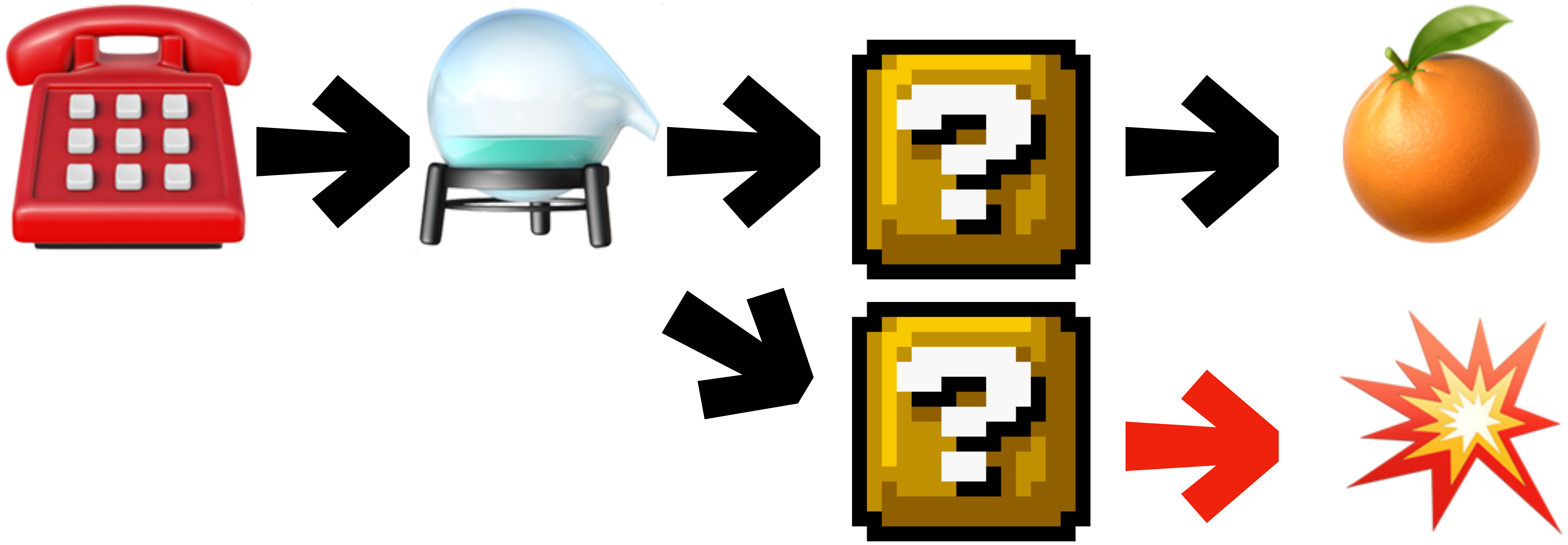

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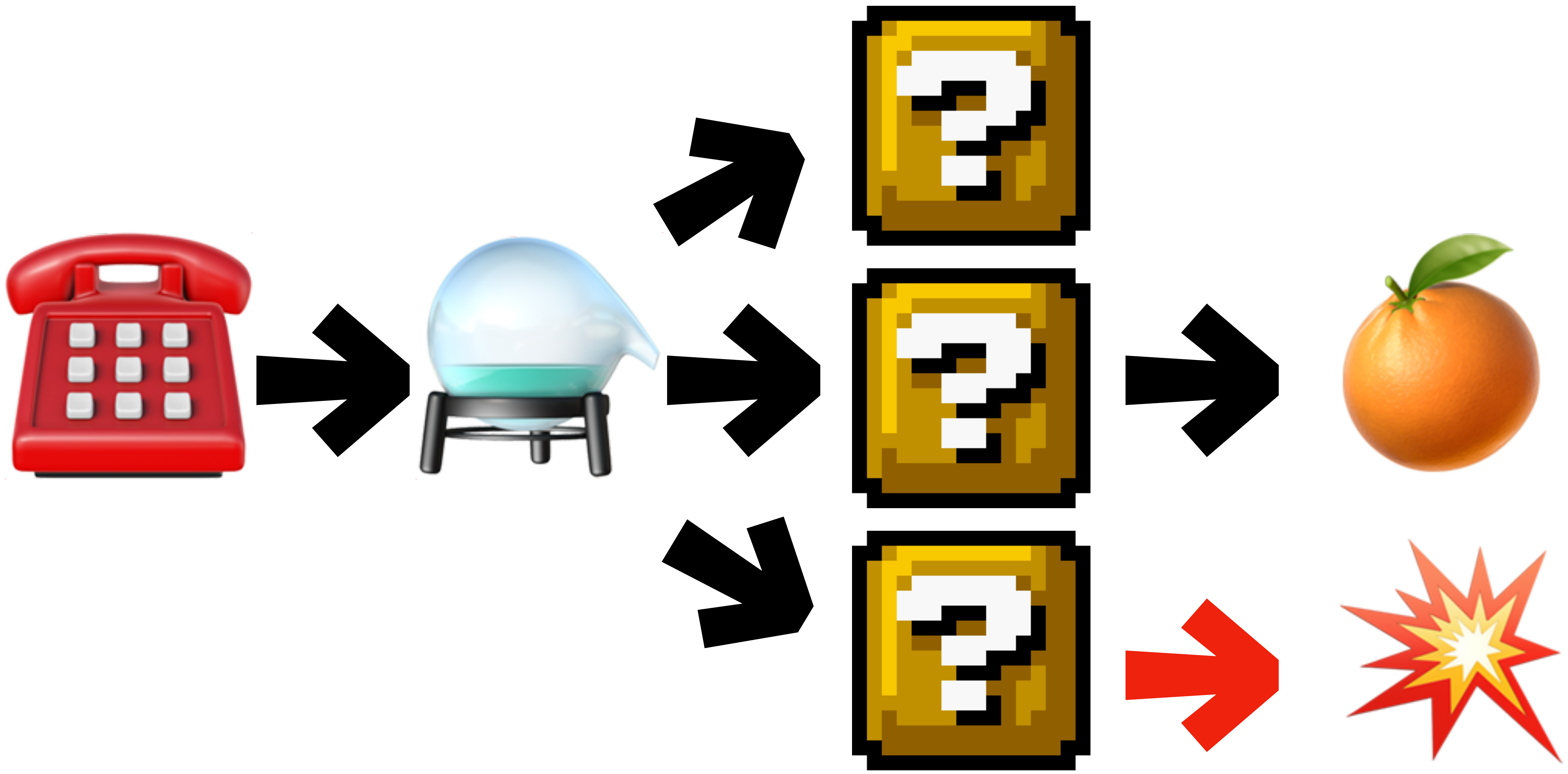

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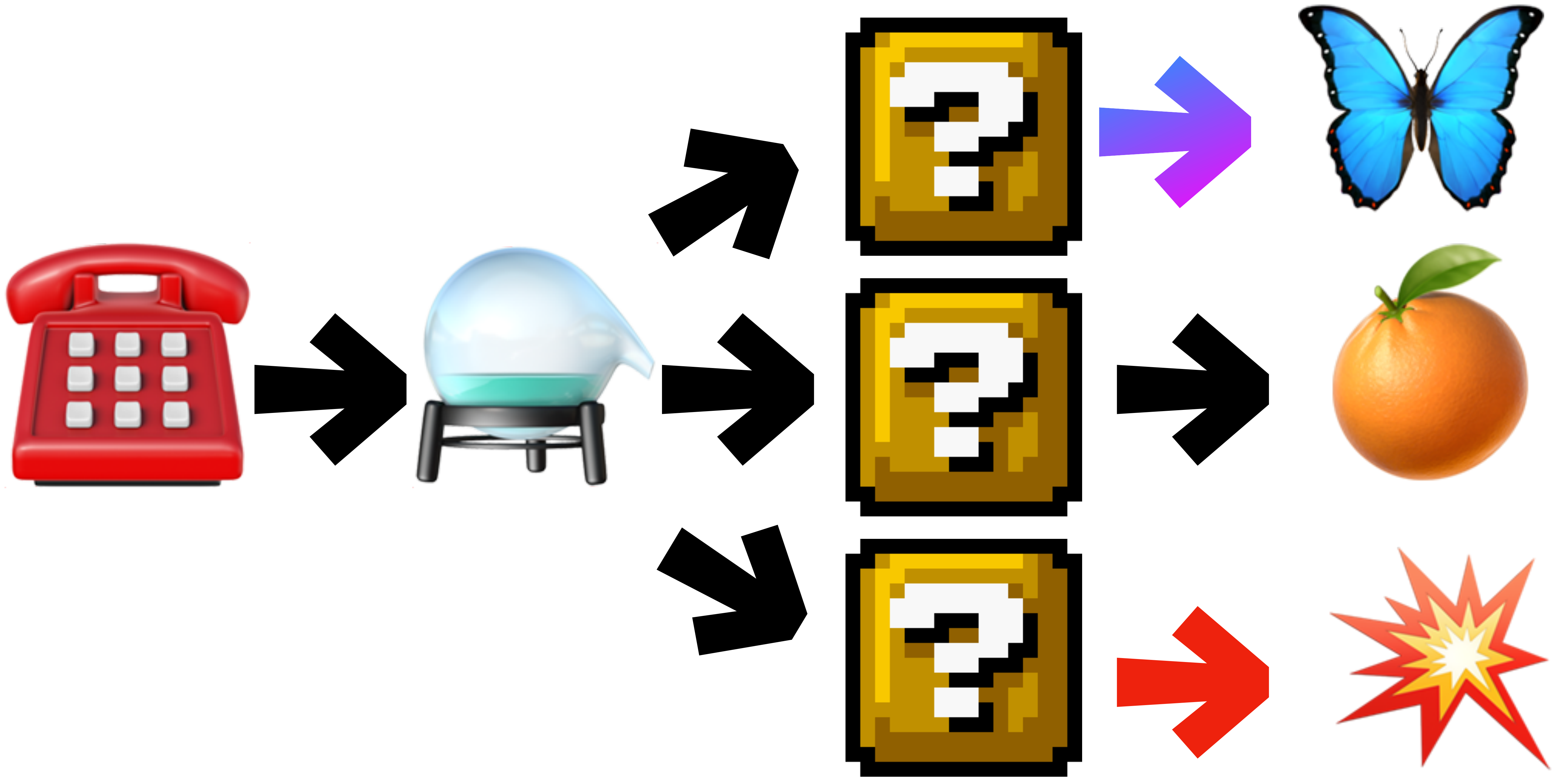

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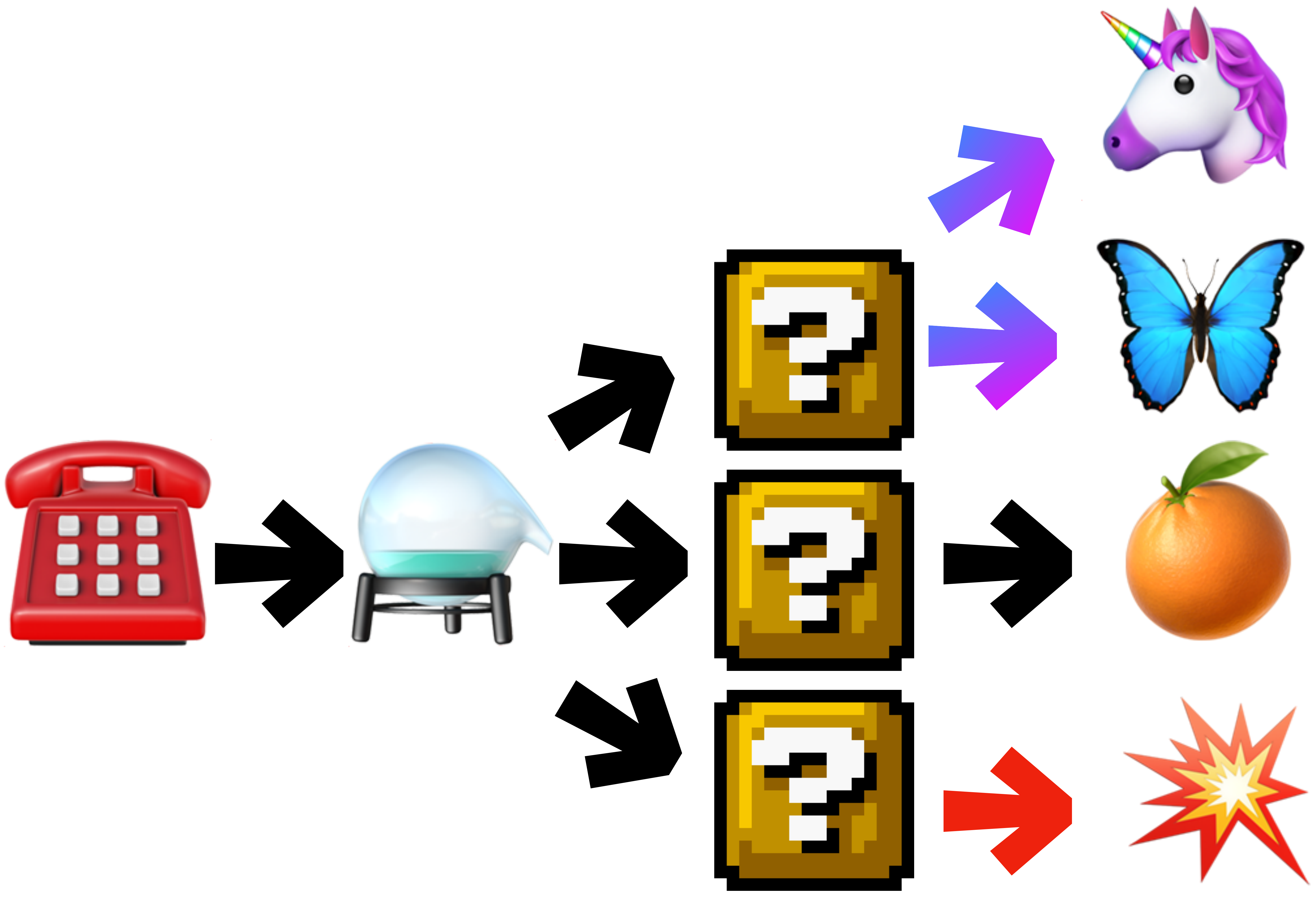

Manifesto ☎️→🔮→❓

Sources of Inspiration

Manifesto ☎️→🔮→❓

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🚀 Things I've seen ***work in production***

Manifesto ☎️→🫧→❓

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- 🦹 ***Criminally*** underused Elixir features

Manifesto ☎️→🔮→❓

Three ***Stupidly Powerful*** *Concepts*

Manifesto ☎️→🔮→❓

Three ***Stupidly Powerful*** *Concepts*

eDSL

Manifesto ☎️→🔮→❓

Three **Stupidly Powerful** Concepts

eDSL

- ***Code as Data***
- ***Managed Effects***
- ***Active Metadata***

Manifesto ☎️→⚗️→❓

Three **Stupidly Powerful** Concepts

eDSL

- ***Code as Data***
  - Expressivity
  - Modular Languages
  - Denotational Design
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Manifesto ☎️→⚗️→

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  - Implicit Concurrency
  - Model Testing
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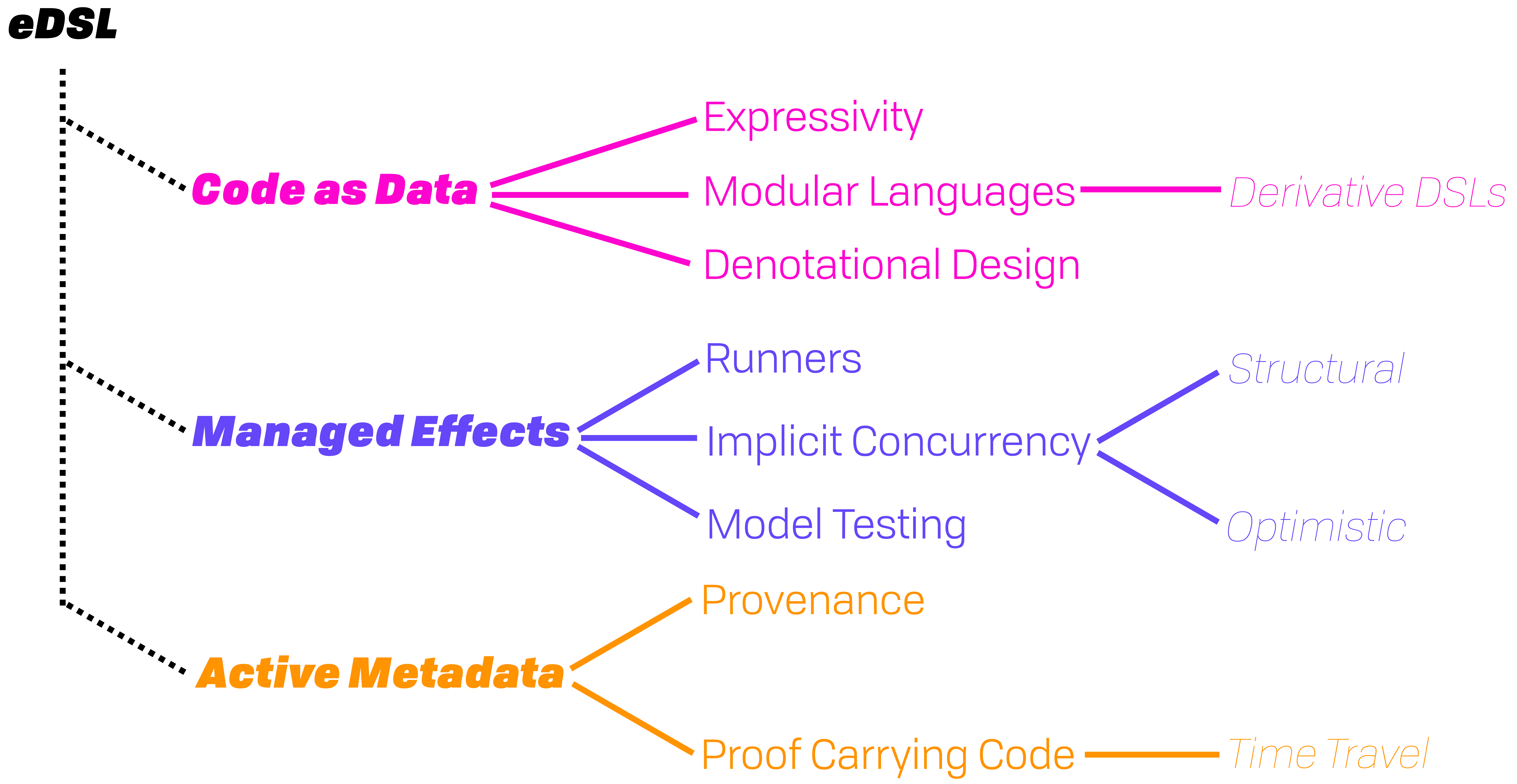
- ***Active Metadata***
  - Provenance
  - Proof Carrying Code

Manifesto ☎️→🔮→❓

Three **Stupidly Powerful** Concepts



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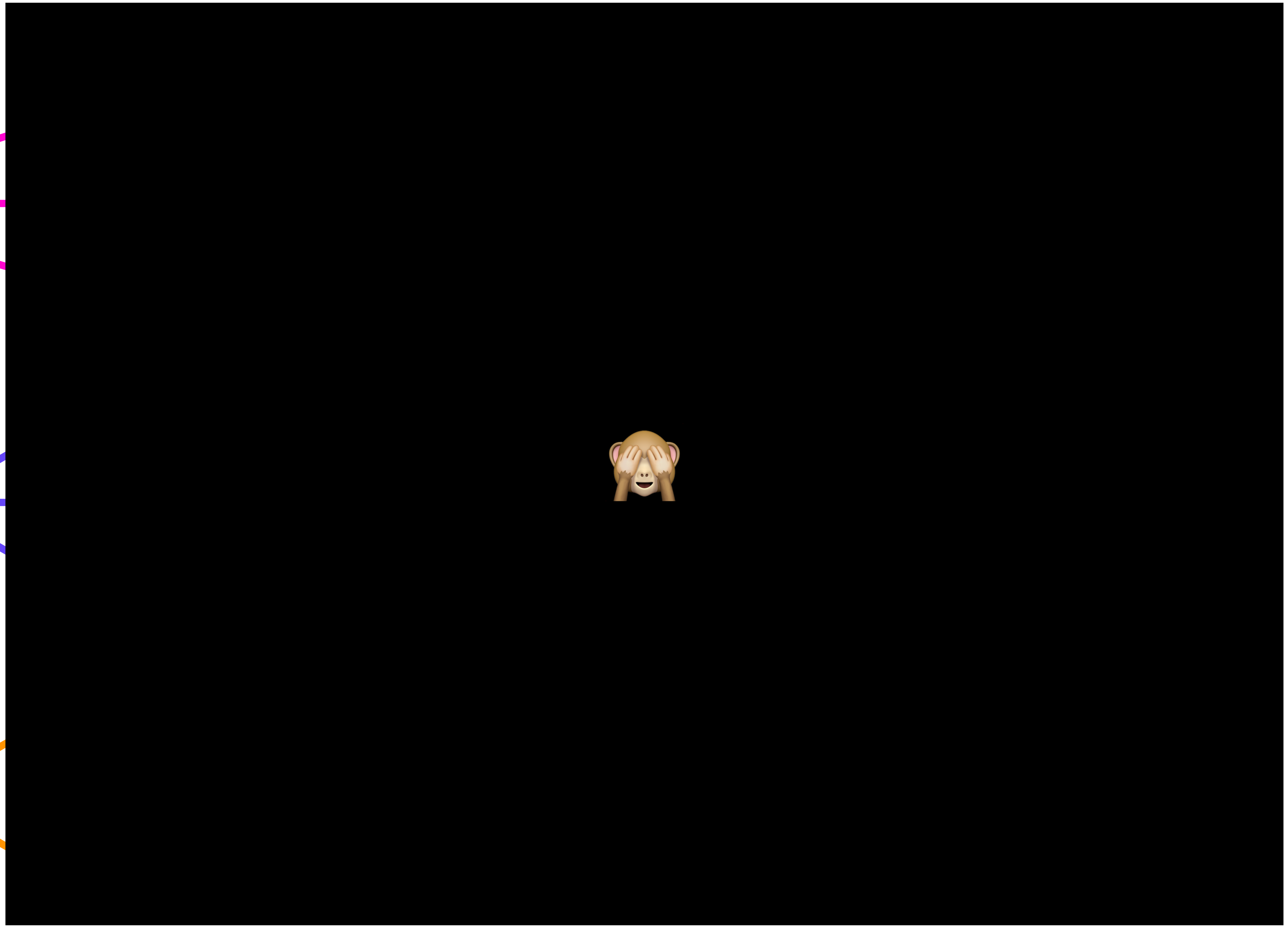

Modular Semantics

Millions of Tiny Languages

Modular Semantics

Millions of Tiny Languages

Millions of Tiny Languages ⚛

We really ***don't want to build*** a programming language from scratch[...], ***let's inherit infrastructure*** from some other language

– Paul Hudak, Building Domain Specific Embedded Languages

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"Some other language" 😏

All the Way Down

All the Way Down

All the Way Down

Binary

Physics

Mathematics

Millions of Tiny Languages ⚛

All the Way Down

Binary

Physics

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Millions of Tiny Languages ⚛

All the Way Down

- Kernel syscalls
- x86 / ARM / RISC-V
- Binary
- Physics
- Mathematics

Millions of Tiny Languages ⚛

All the Way Down

Elixir AST

BEAM bytecode

Kernel syscalls

x86 / ARM / RISC-V

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Millions of Tiny Languages ⚛

All the Way Down

- Application Domain
- Library / Framework
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Millions of Tiny Languages ⚛

All the Way Down

- Natural Language
- GUI Metaphor
- Application Domain
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- Elixir AST
- BEAM bytecode
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- Physics
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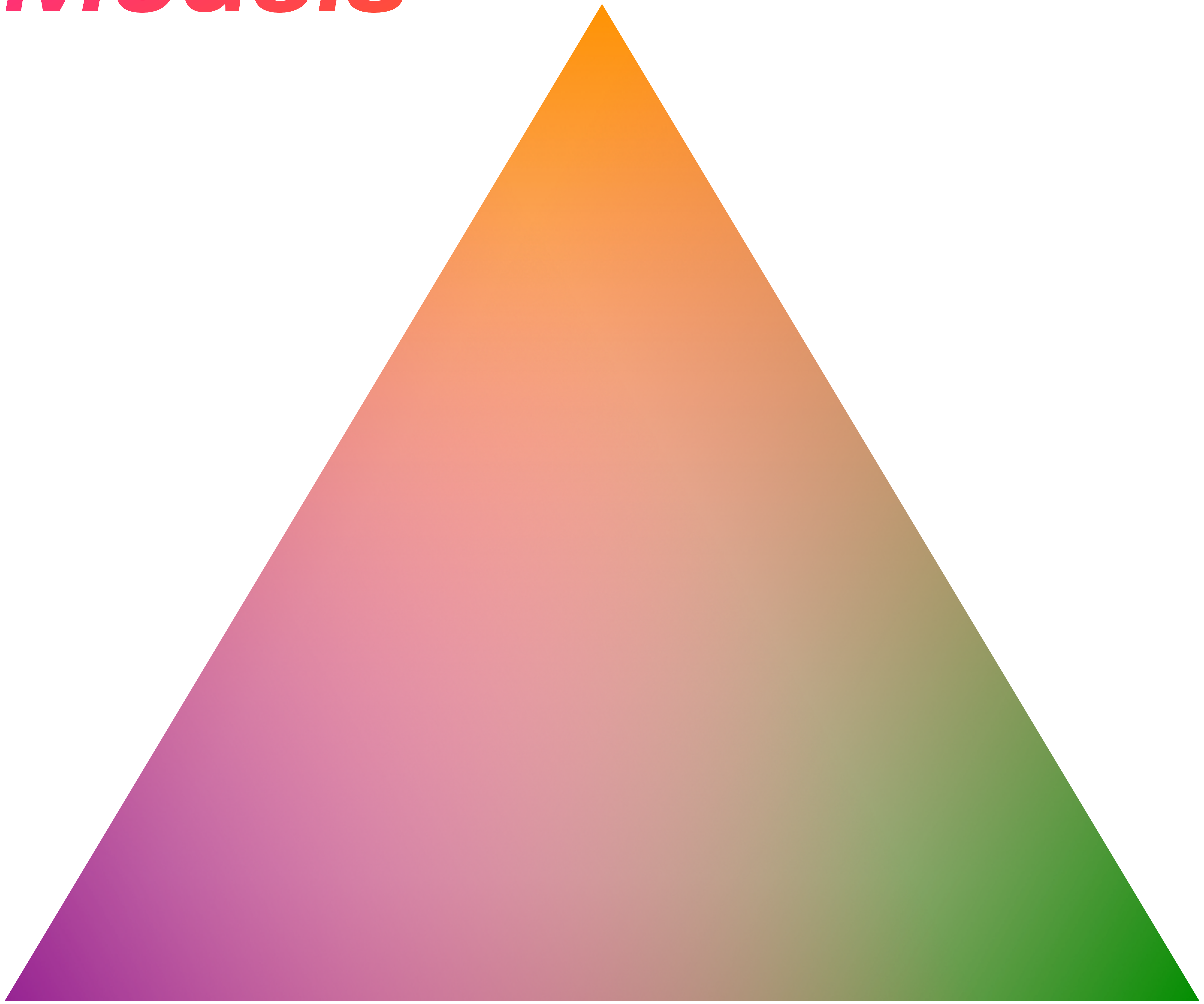
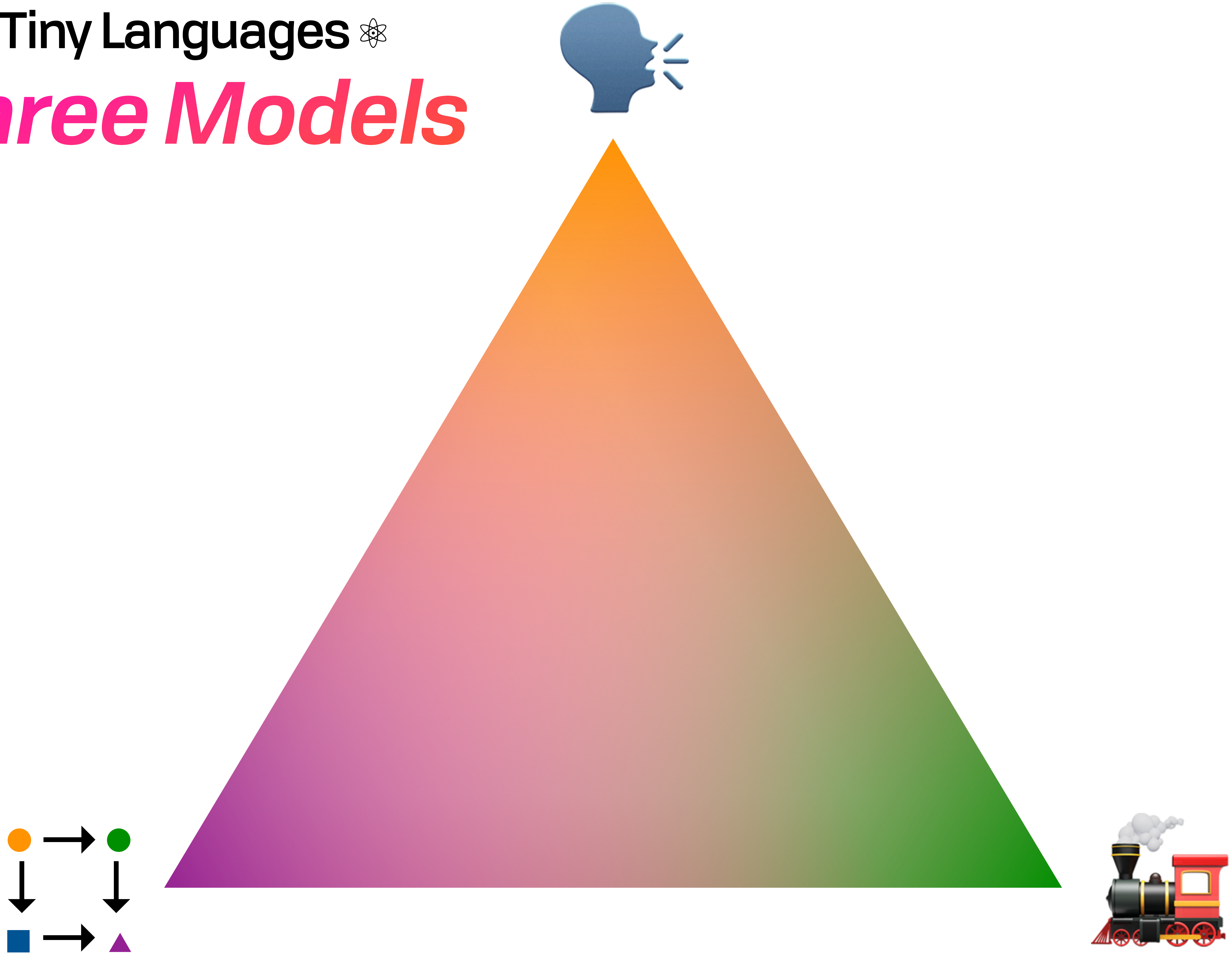
Big Three Models

Big Three Models



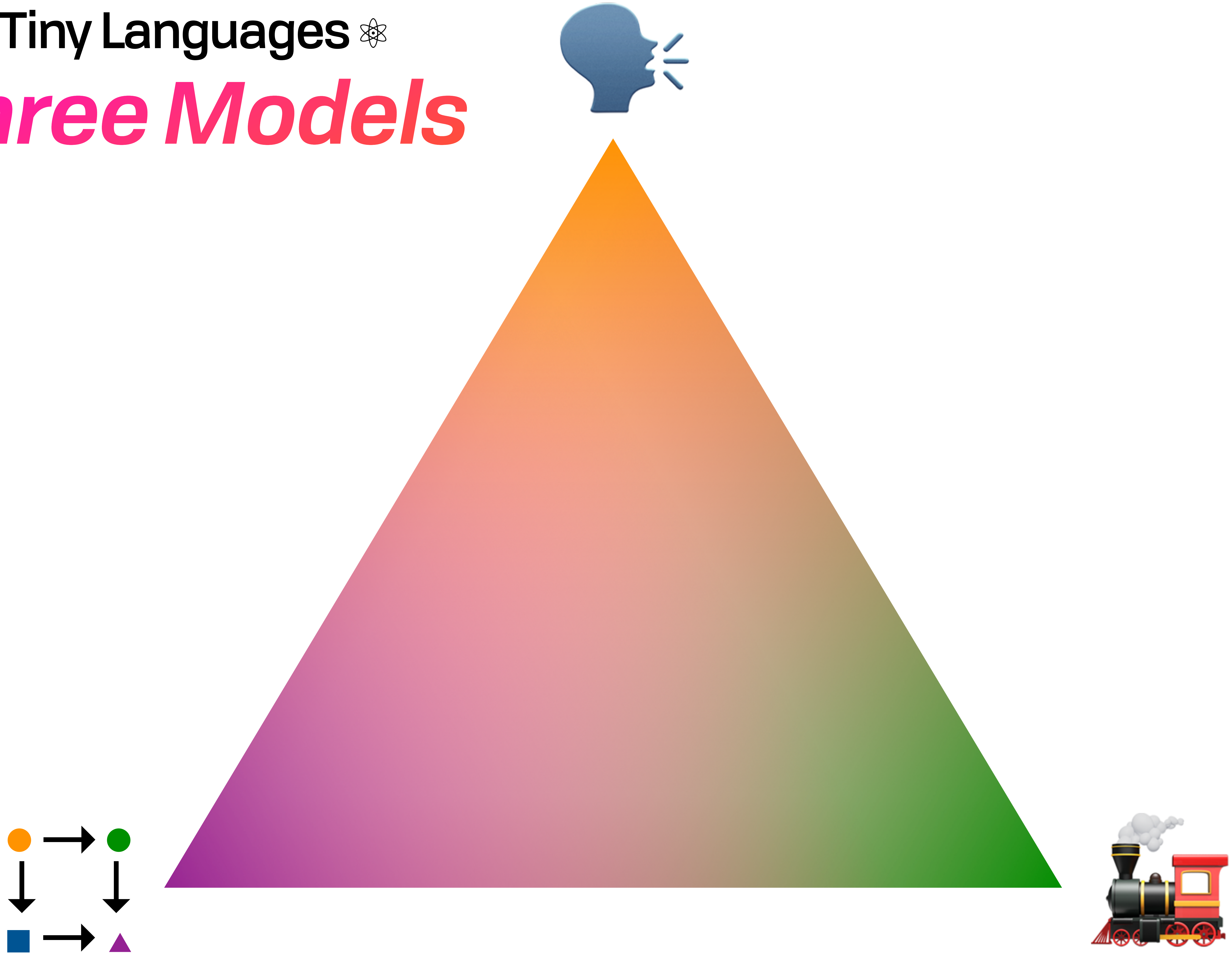
Millions of Tiny Languages ⚛

Big Three Models



Millions of Tiny Languages ⚛

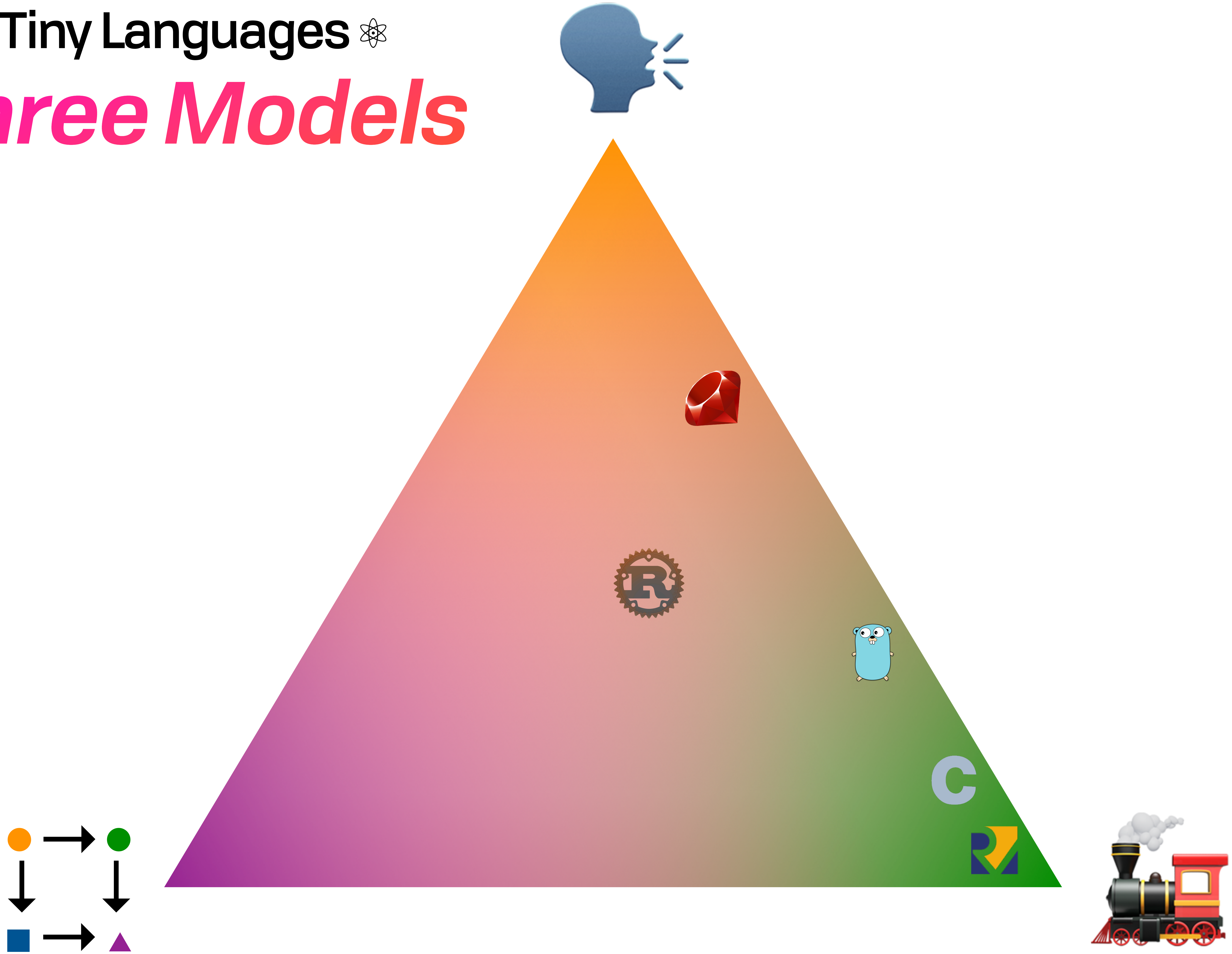
Big Three Models



Dynamic
Operational
Mechanical

Millions of Tiny Languages

Big Three Models



Dynamic
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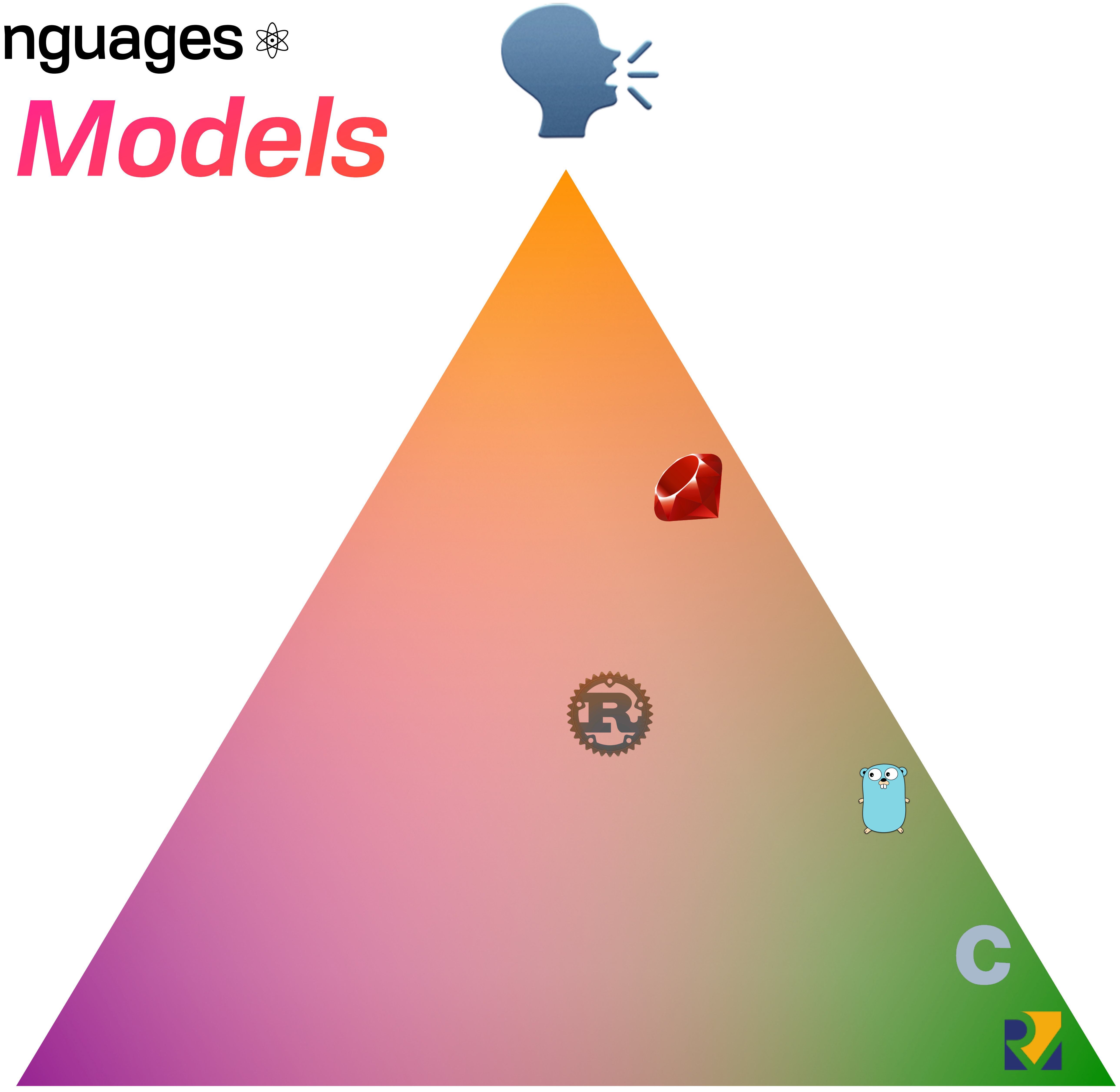
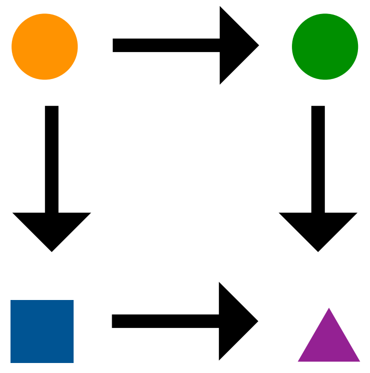
Millions of Tiny Languages ⚛

Big Three Models



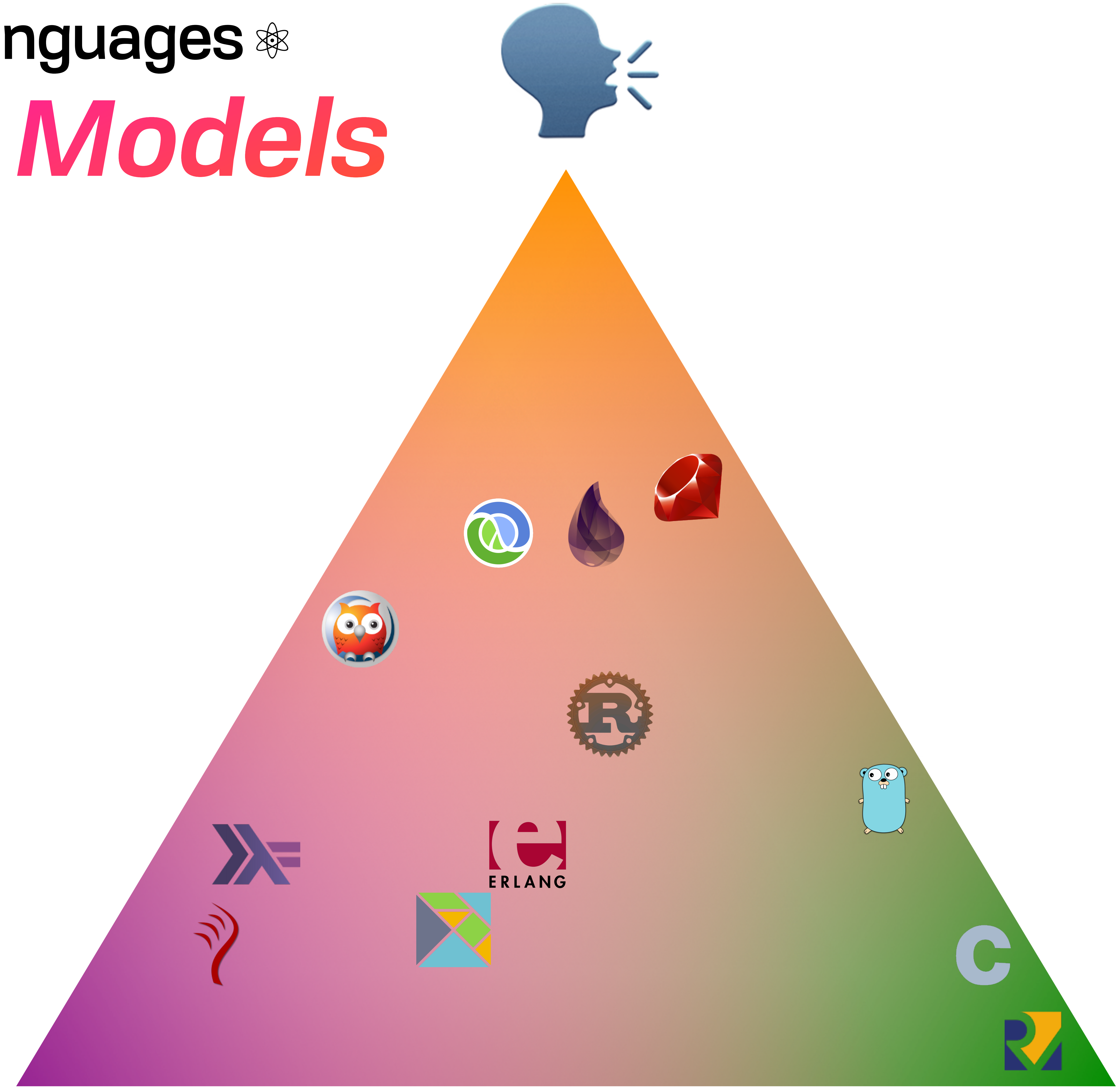
Universal
Denotational
Mathematical



Dynamic
Operational
Mechanical

Millions of Tiny Languages

Big Three Models



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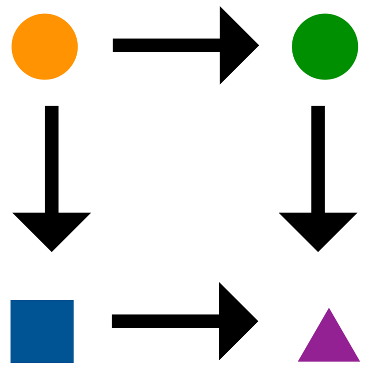


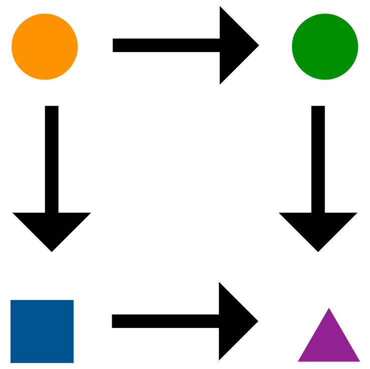
Dynamic
Operational
Mechanical

Millions of Tiny Languages ⚛

Big Three Models

Symbolist
Semiotic
Natural Language

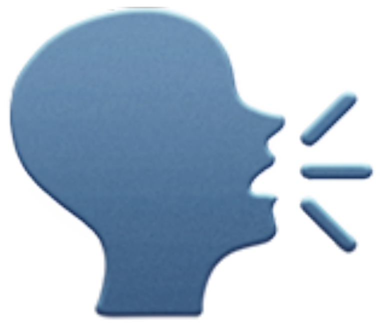
Universal
Denotational
Mathematical



Dynamic
Operational
Mechanical

Millions of Tiny Languages ⚛

Big Three Models



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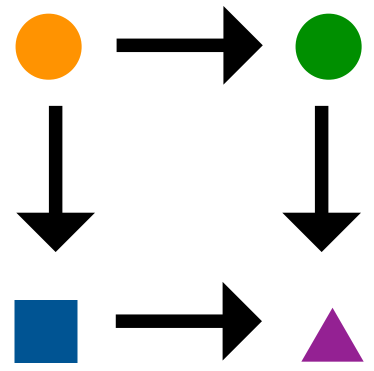
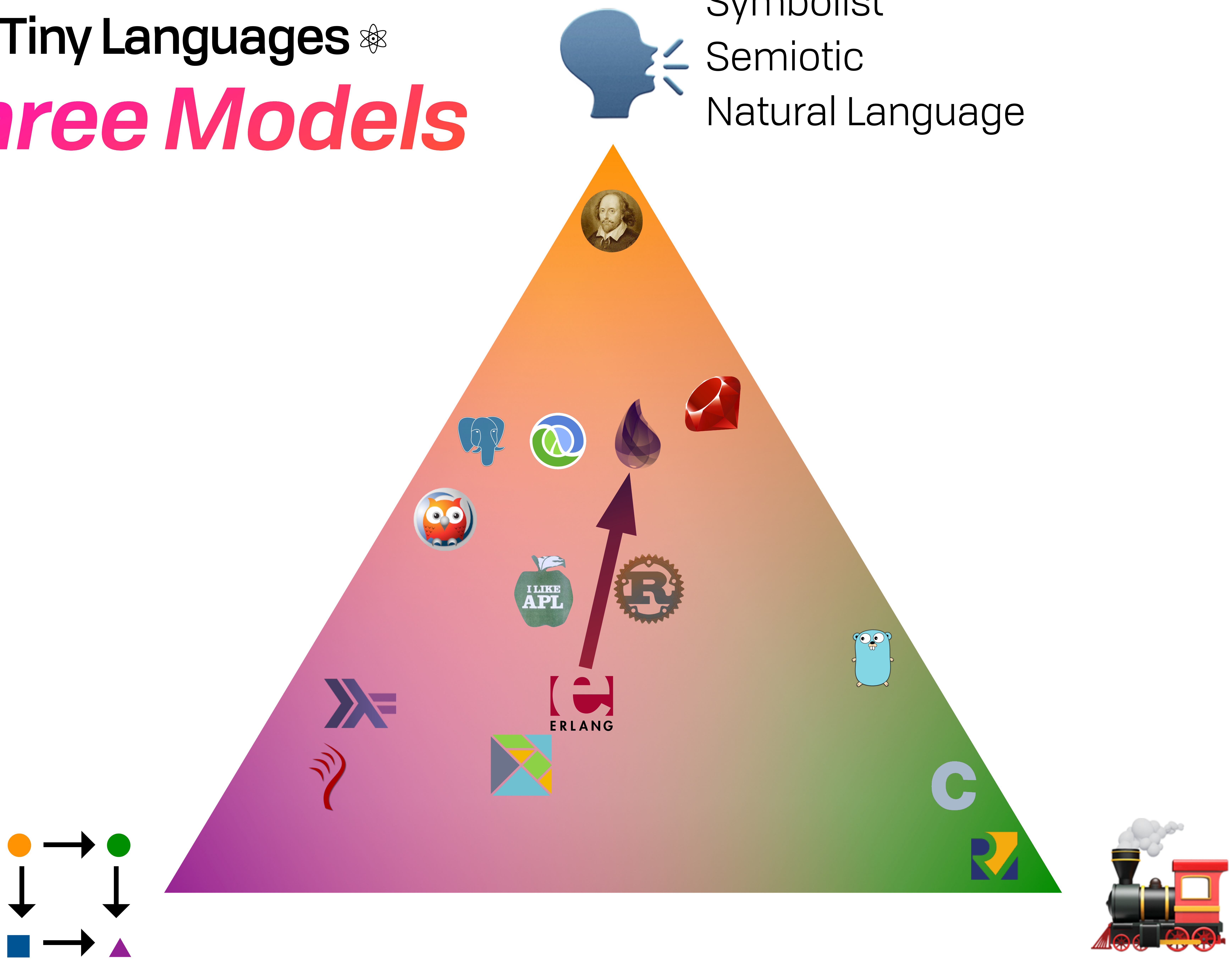


Dynamic
Operational
Mechanical

Millions of Tiny Languages ⚛

Big Three Models



Millions of Tiny Languages ⚛

Big Three Models

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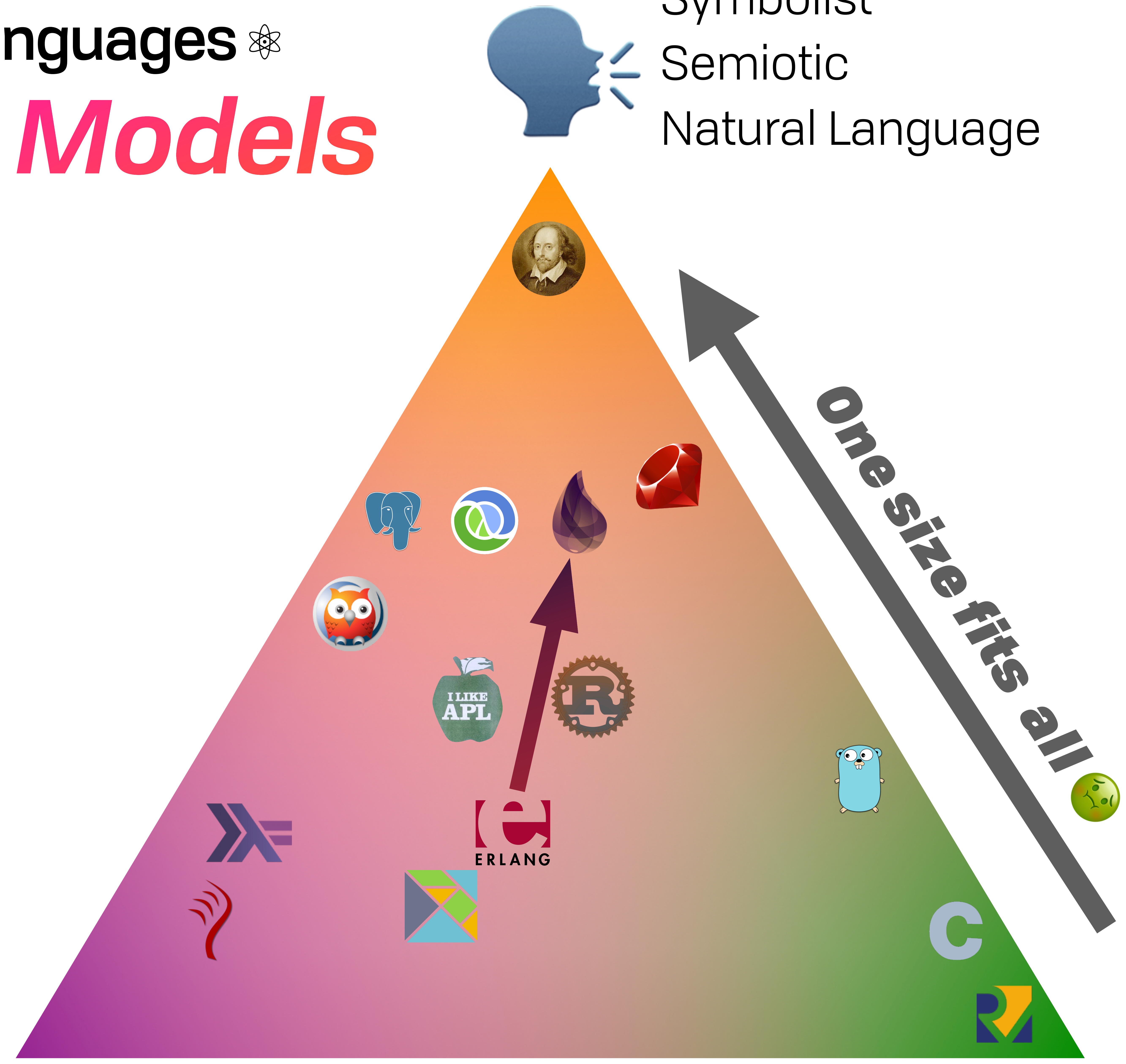
Semiotic
Natural Language



Universal
Denotational
Mathematical

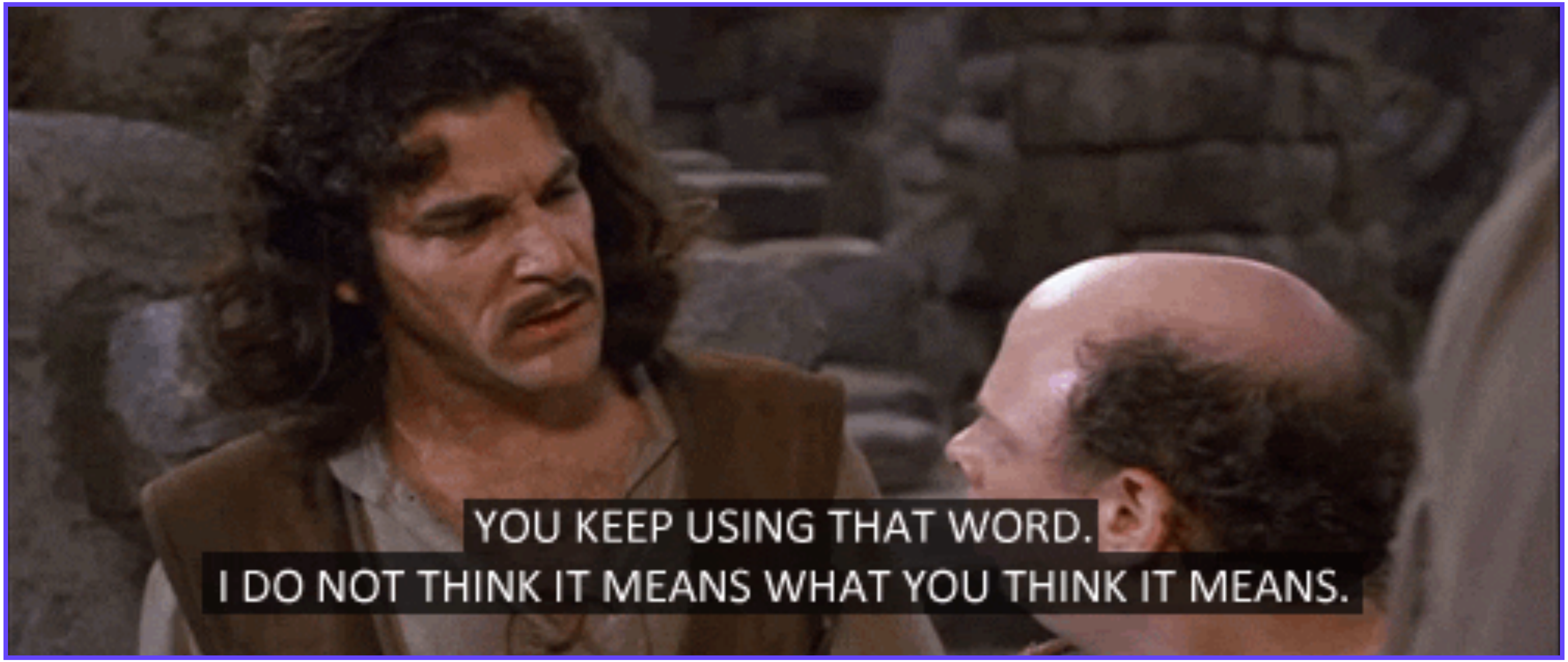
Dynamic
Operational
Mechanical

Millions of Tiny Languages ⚛

Big Three Models

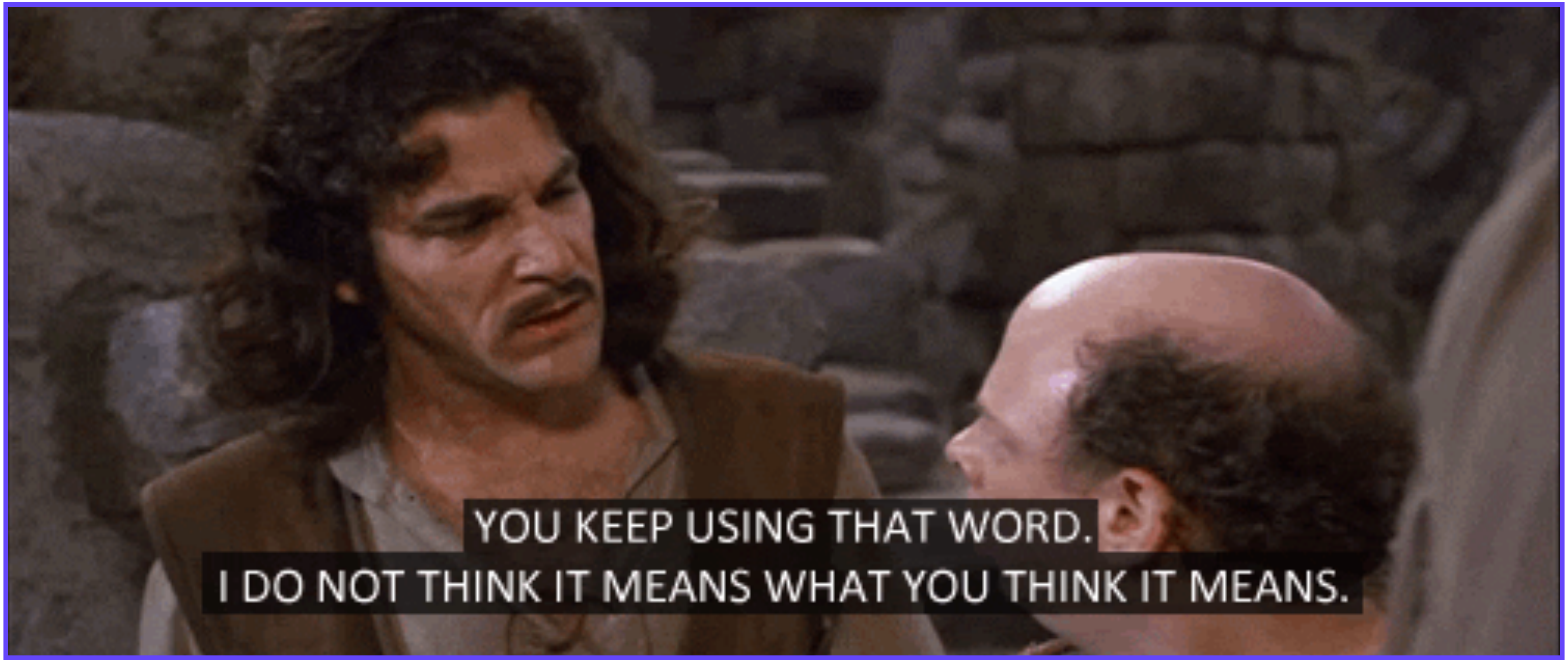
Manifesto ☎️→🔮→❓

"Expressive" 🔥⚔️🐉🙈



Manifesto ☎️→🔮→❓

"Expressive" 🔥⚔️🐉🙈



Tower of (Expressive) Power

Tower of (Expressive) Power

```
5 + 10
5 - 10
5 * 10
5 ^ 10
mod 5 10
```

Tower of (Expressive) Power

```
5 + 10
5 - 10
5 * 10
5 ^ 10
mod 5 10
```

```
x = 5
y = 10
```

Tower of (Expressive) Power

```
5 + 10
5 - 10
5 * 10
5 ^ 10
mod 5 10
```

```
x = 5
y = 10
```

```
x = 5
y = 10
x = x + y
```

Tower of (Expressive) Power

```
5 + 10
5 - 10
5 * 10
5 ^ 10
mod 5 10
```

```
x = 5
y = 10
```

```
x = 5
y = 10
x = x + y
```

```
while(x == false) {
  // ...
}
```

Millions of Tiny Languages ⚛

Tower of (Expressive) Power

```
5 + 10
5 - 10
5 * 10
5 ^ 10
mod 5 10
```

```
x = 5
y = 10
```

```
x = 5
y = 10
x = x + y
```

```
def forever(action) do
  action
  forever(action)
end
```

```
while(x == false) {
  // ...
}
```

Millions of Tiny Languages

Tower of (Expressive) Power

```
5 + 10
5 - 10
5 * 10
5 ^ 10
mod 5 10
```

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x = 5
y = 10
```

```
x = 5
y = 10
x = x + y
```

```
def forever(action) do
  action
  forever(action)
end
```

```
while(x == false) {
  // ...
}
```

```
def evens([]), do: []
def evens([x | xs]), do: [x | odds(xs)]

def odds ([]), do: []
def odds([_ | xs]), do: evens(xs)
```

Millions of Tiny Languages

Tower of (Expressive) Power

```
5 + 10
5 - 10
5 * 10
5 ^ 10
mod 5 10
```

```
x = 5
y = 10
```

```
x = 5
y = 10
x = x + y
```

```
while(x == false) {
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```
def forever(action) do
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  forever(action)
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```

```
def evens([]), do: []
def evens([x | xs]), do: [x | odds(xs)]

def odds ([]), do: []
def odds([_ | xs]), do: evens(xs)
```

```
iex(7)> evens([1,2,3,4,5])
[1, 3, 5]
iex(8)> odds([1,2,3,4,5])
[2, 4]
```

Practical Bounds

Practical Bounds

Can a language be ***too expressive?***

Millions of Tiny Languages

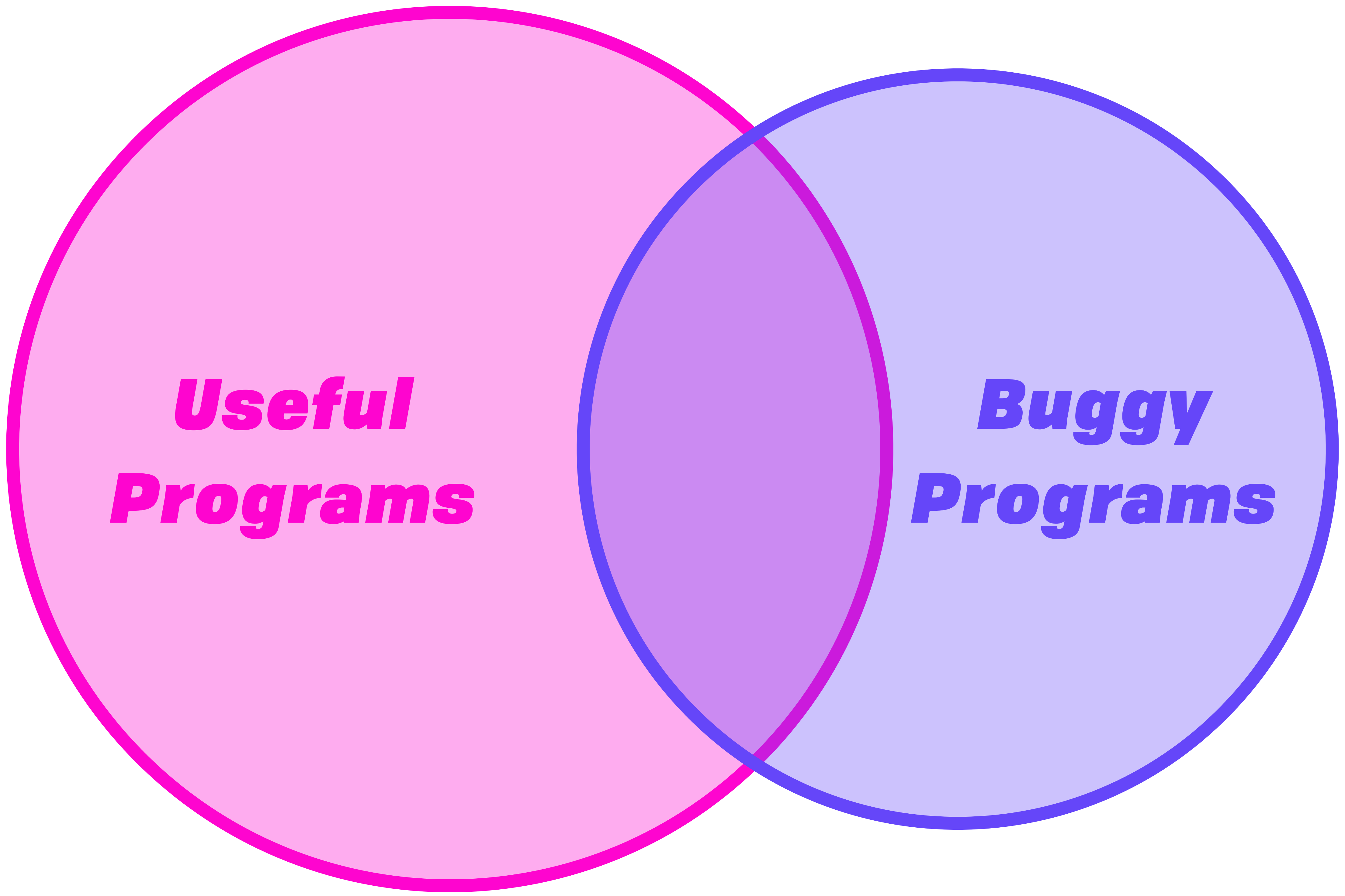
Practical Bounds

Can a language be ***too expressive?***

Millions of Tiny Languages

Practical Bounds

Can a language be ***too expressive?***



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Practical Bounds

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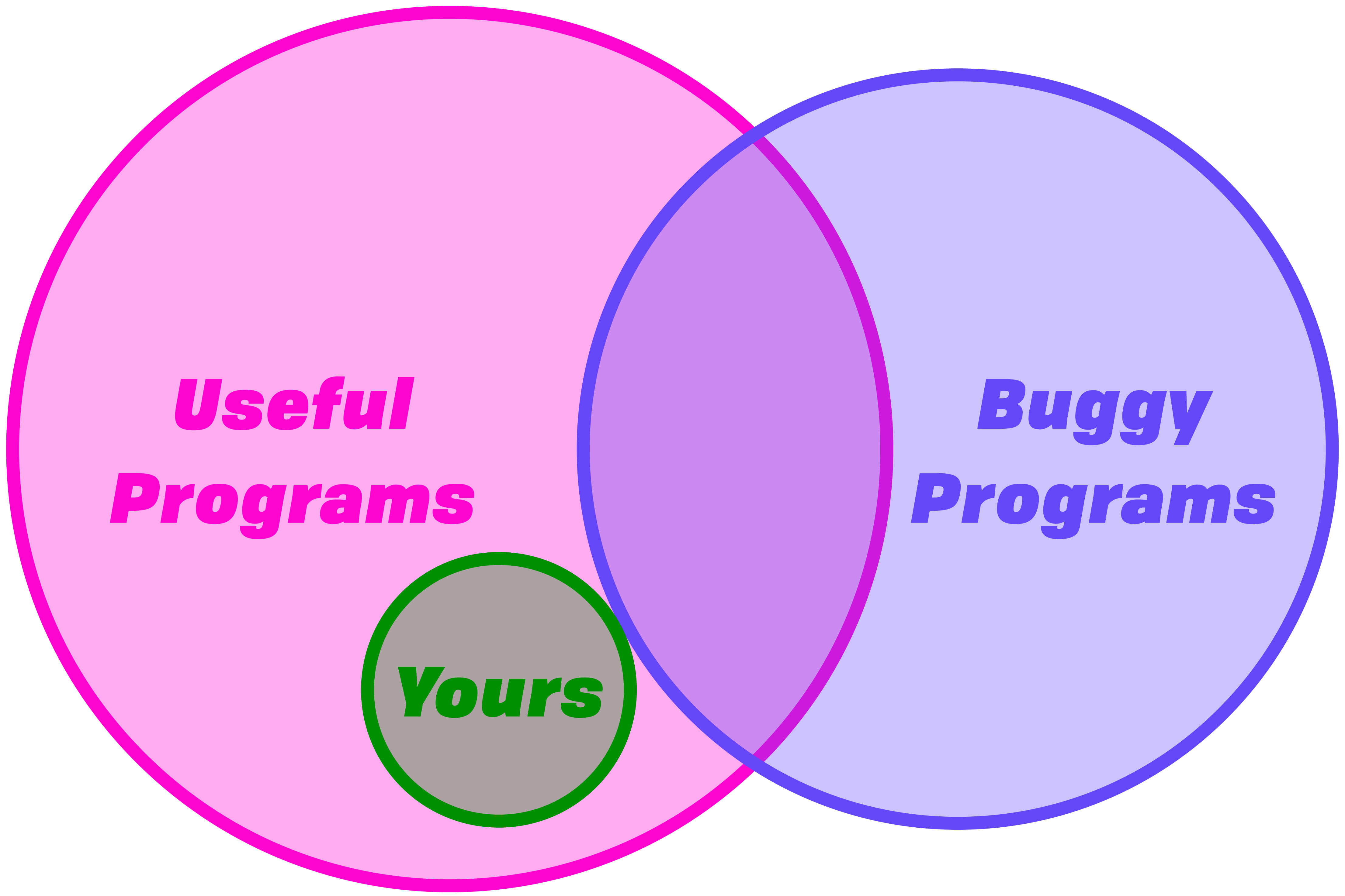

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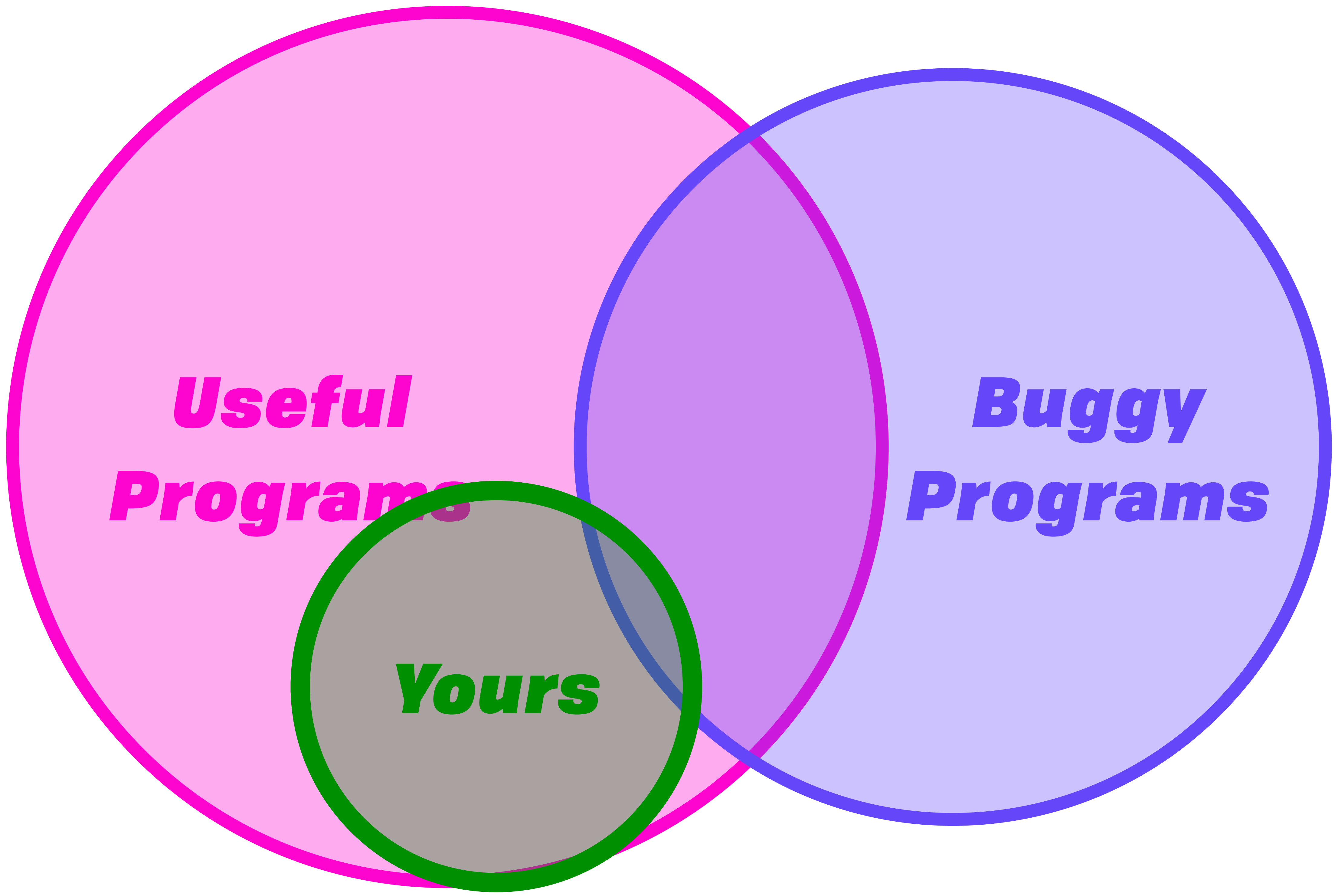
Practical Bounds

Can a language be ***too expressive?***



Welcome to the Danger Zone ⚠️

```
System.halt()
```

```
Evil.goto(10)
```

What's So Bad About Control? 🦶🔫

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What's So Bad About Control? 🦶🔫

Line 1

Line 2

Line 3

Line 4

Line 5 – GOTO

Line 6

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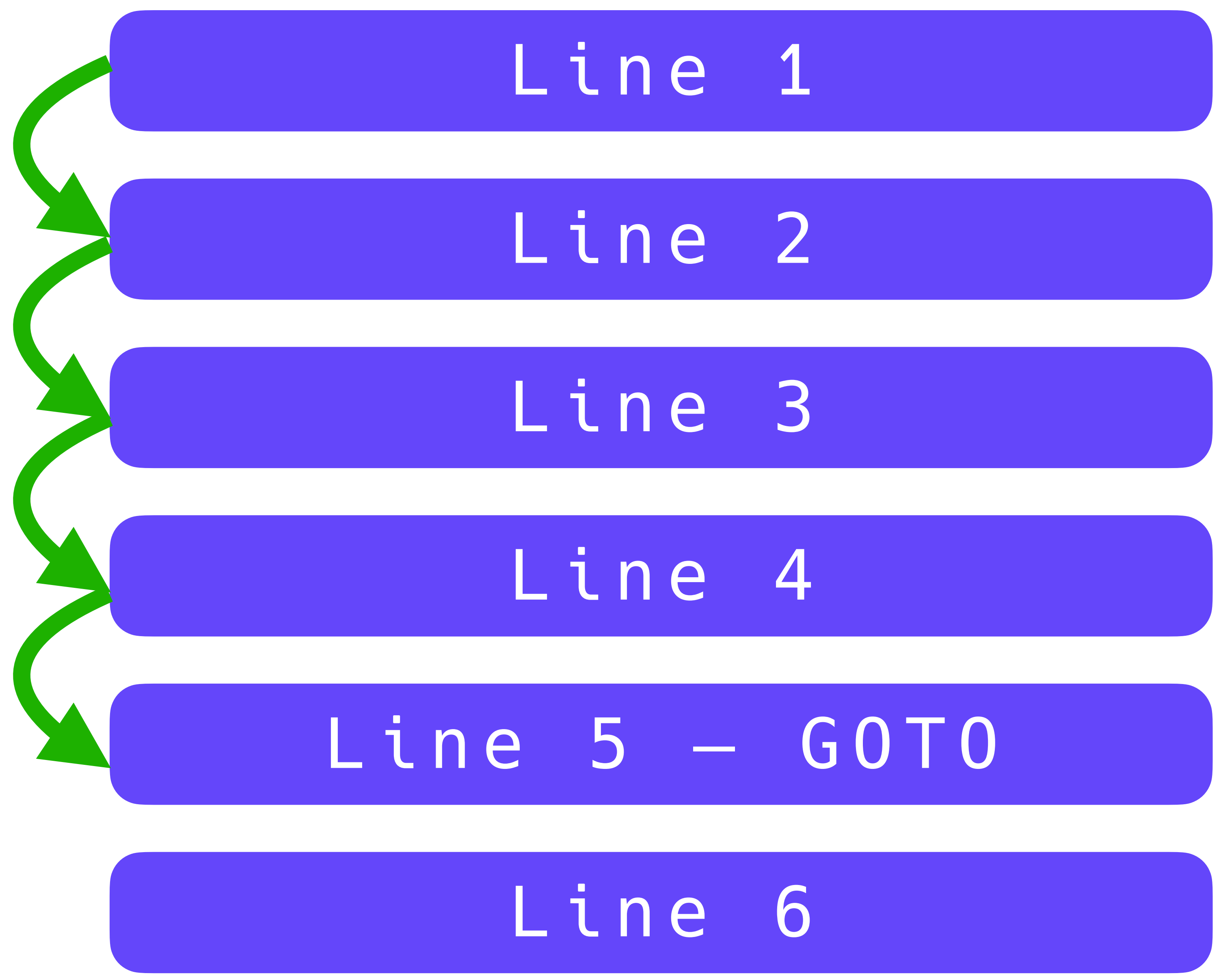
What's So Bad About Control? 🦶🔫



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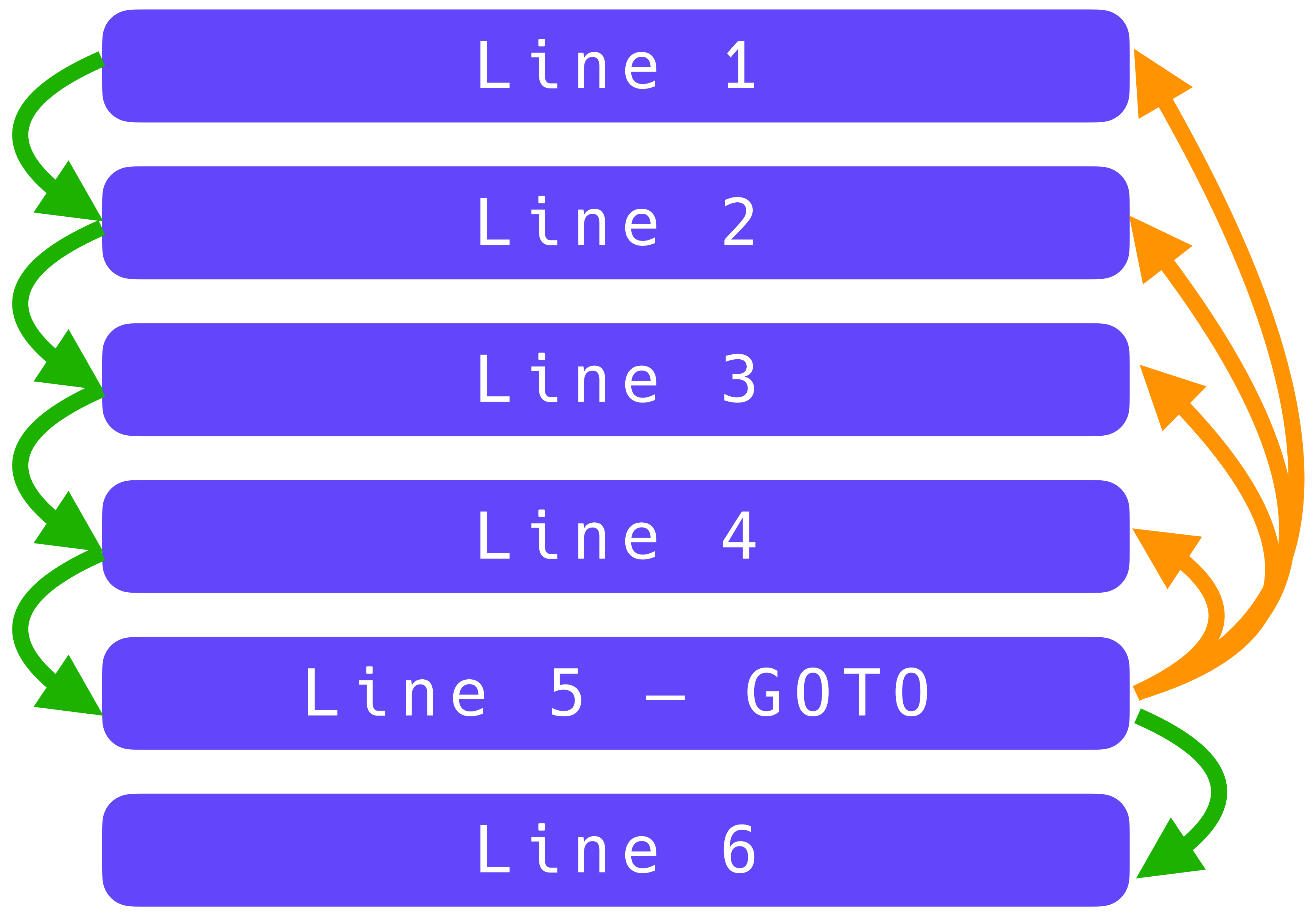
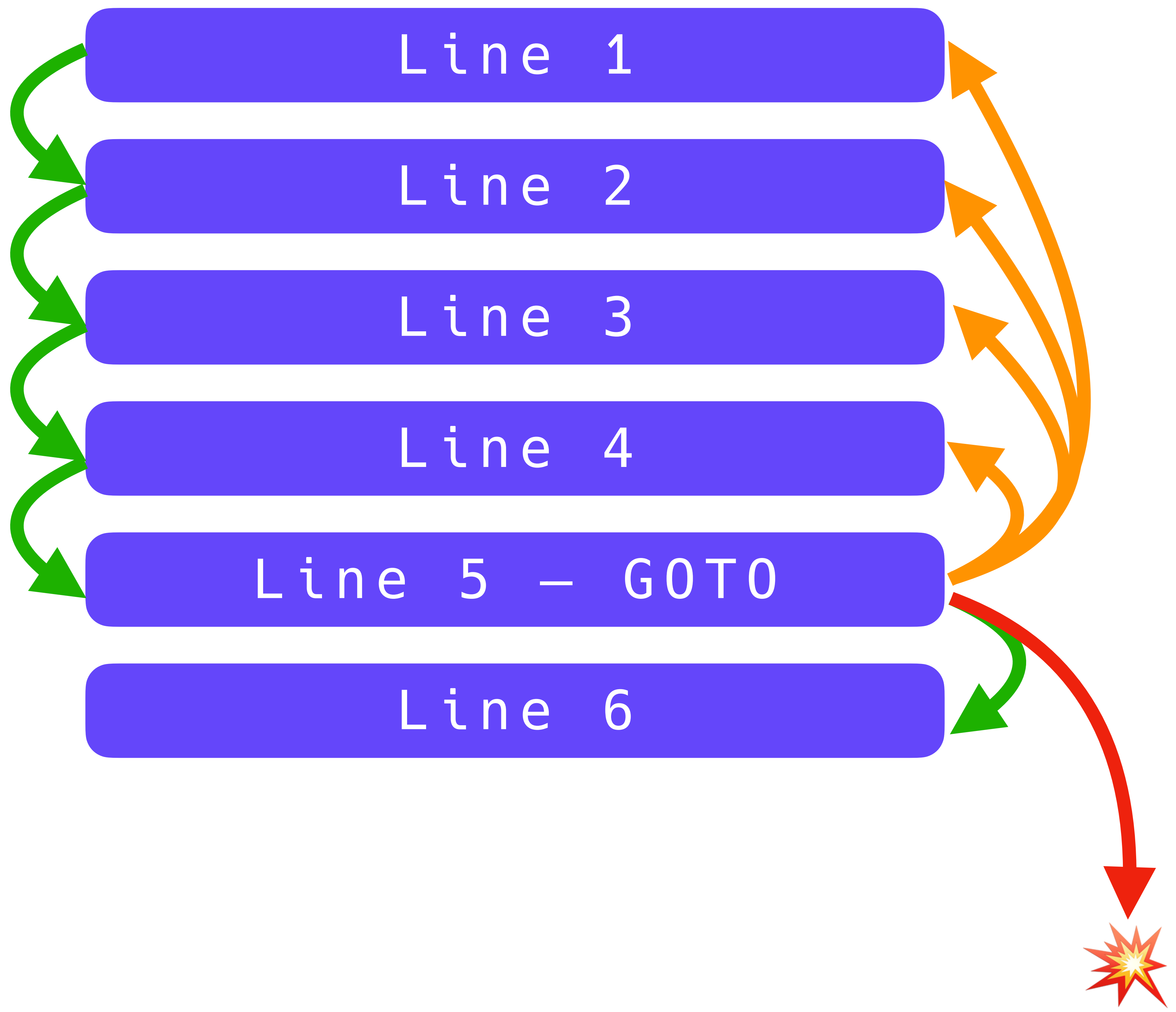
What's So Bad About Control? 🦶🔫



What's So Bad About Control? 🦶🔫

Turing completeness ***considered harmful***



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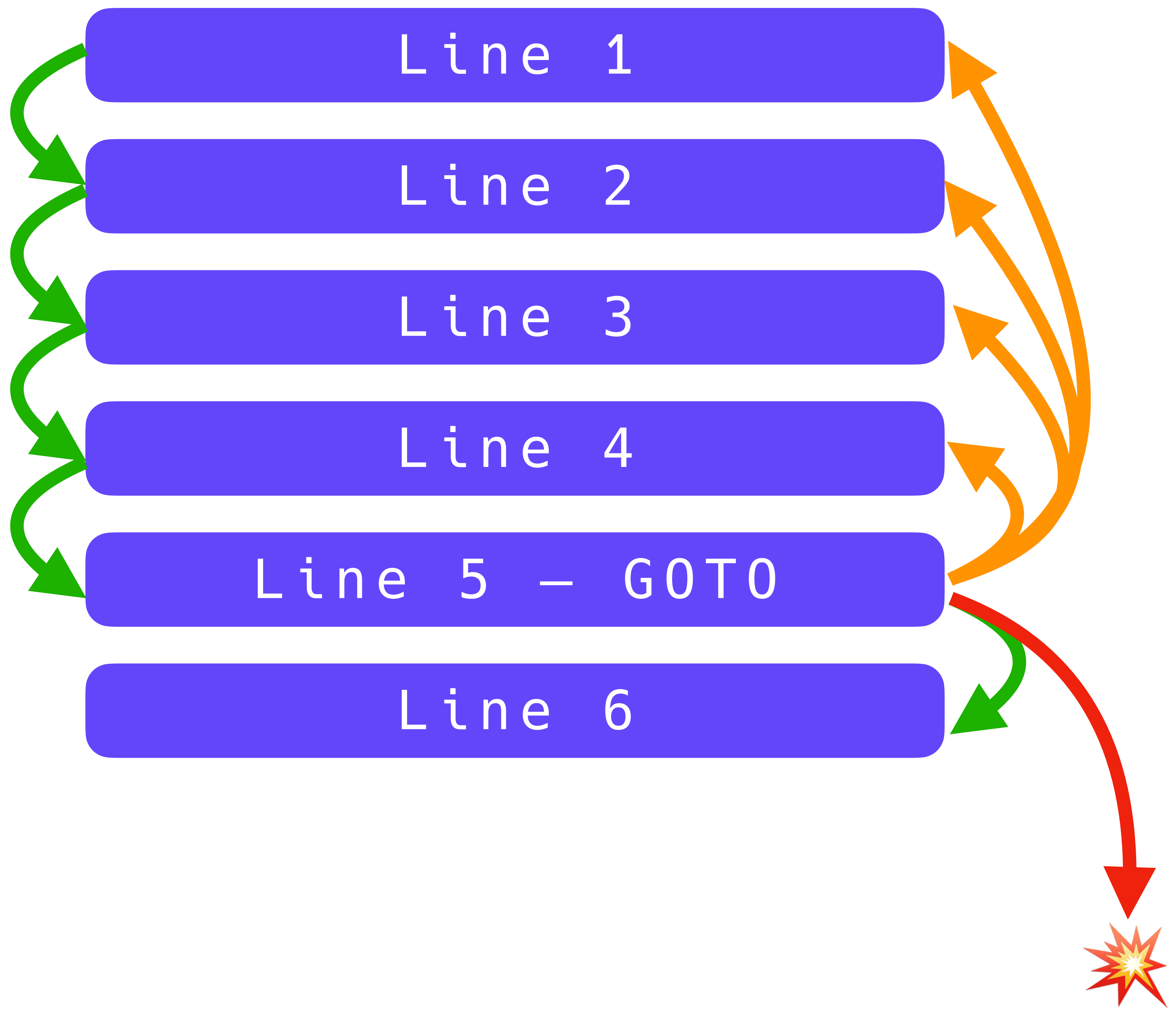
What's So Bad About Control? 🦶🔫

Turing completeness ***considered harmful***



Aside: "Accidentally" Turing Complete

https://harrisonwl.github.io/assets/courses/malware/spring2017/papers/mov-is-turing-complete.pdf
https://github.com/ealter/vim_turing_machine
https://github.com/Microsoft/TypeScript/issues/14833
https://vanbever.eu/pdfs/vanbever_turing_icnp_2013.pdf
https://arxiv.org/pdf/1904.09828.pdf
https://softwareengineering.stackexchange.com/a/136179

Aside: "Accidentally" Turing Complete

- x86 MOV (just by itself)
- Vim Normal Mode
- BGP
- Peano arithmetic
- Musical Notation
- Sendmail's Config
- TypeScript's Type System
- Magic the Gathering
- Pokemon Yellow
- Unicode (conjectured)

https://harrisonwl.github.io/assets/courses/malware/spring2017/papers/mov-is-turing-complete.pdf
https://github.com/ealter/vim_turing_machine
https://github.com/Microsoft/TypeScript/issues/14833
https://vanbever.eu/pdfs/vanbever_turing_icnp_2013.pdf
https://arxiv.org/pdf/1904.09828.pdf
https://softwareengineering.stackexchange.com/a/136179

Millions of Tiny Languages ⚛️

The Lesson 👩‍🏫

The Lesson 👩‍🏫

The bottom line is that
the ***more powerful a language***
(i.e. the more that is possible within the language),
the ***harder it is to understand*** systems
constructed in it

– Ben Mosley & Peter Marks, Out of the Tarpit

Three Focused Vocabularies

Millions of Tiny Languages ⚛

Three Focused Vocabularies

```elixir
defprotocol ImageManipulation do
  @spec rotate(t, non_neg_integer()) :: t
  def rotate(image, degrees)

  @spec scale(t, integer()) :: t
  def scale(image, percentage)

  @spec translate(t, integer(), non_neg_integer()) :: t
  def translate(image, degrees, distance_in_pixels)
end
```

Millions of Tiny Languages

Three Focused Vocabularies

```elixir
defprotocol RadialGameMovement do
  @spec move(t, integer(), non_neg_integer()) :: t
  def move(entity, degrees, paces)
end
```

```elixir
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  @spec rotate(t, non_neg_integer()) :: t
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  @spec move(t, integer(), non_neg_integer()) :: t
  def move(entity, degrees, paces)
end
```

```elixir
defprotocol GameActions do
  @type direction :: :north | :south | :east | :west

  @spec move(t, direction(), non_neg_number()) :: t
  def move(entity, direction, paces)

  @spec speak(t, String.t()) :: t
  def speak(entity, message)

  @spec listen(t, t) :: {t, String.t()}
  def listen(entity, entity)
end
```

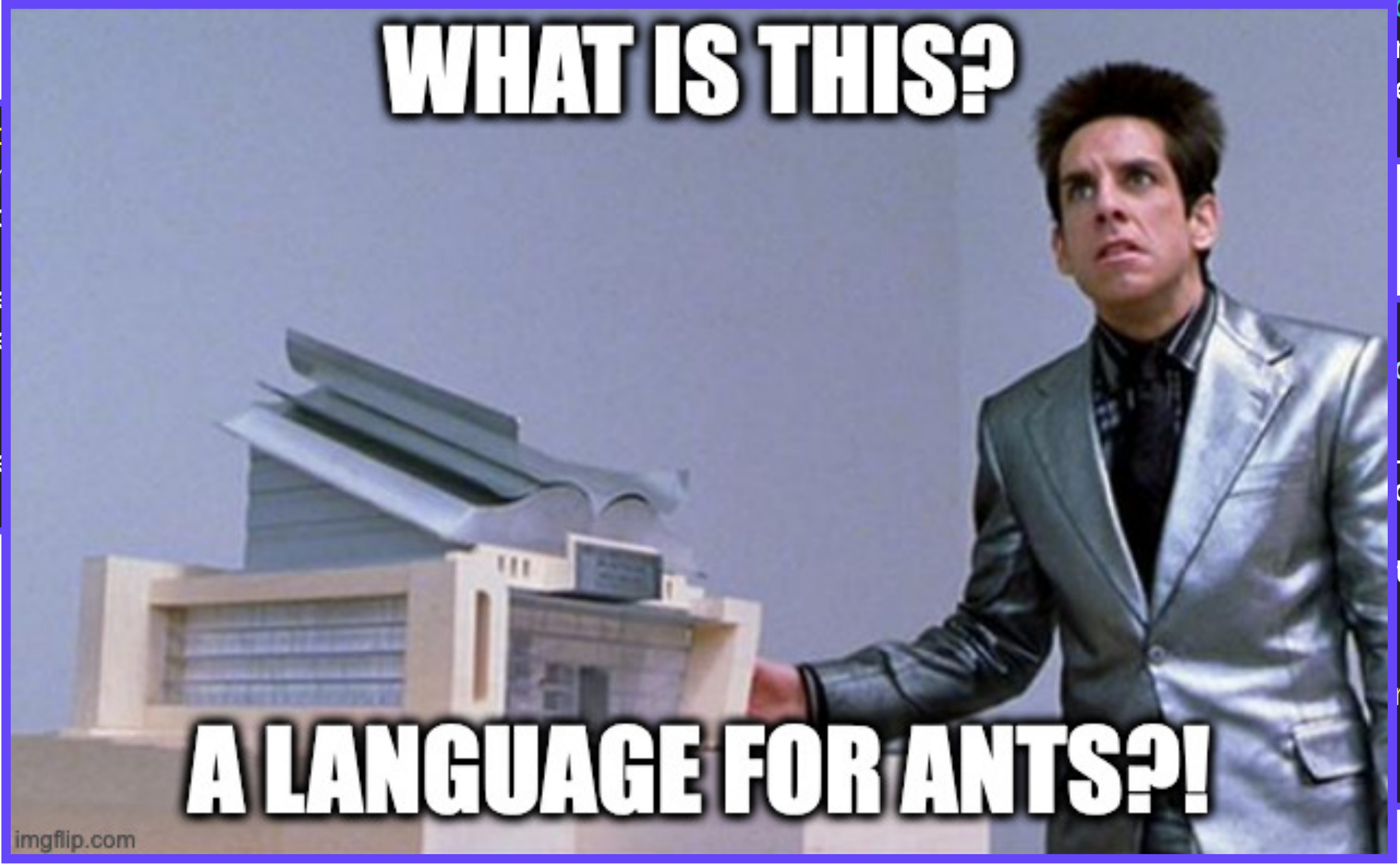
Millions of Tiny Languages

Three Focused Vocabularies

```
defprotocol ImageMani
  @spec rotate(t, non
  def rotate(image, d

  @spec scale(t, inte
  def scale(image, pe

  @spec translate(t,
  def translate(image
end
```




```
do
neg_integer()) :: t
es)
```

```
outh | :east | :west

_neg_number()) :: t
ces)

t

ng.t())
```

Compositional Vocabularies

Millions of Tiny Languages

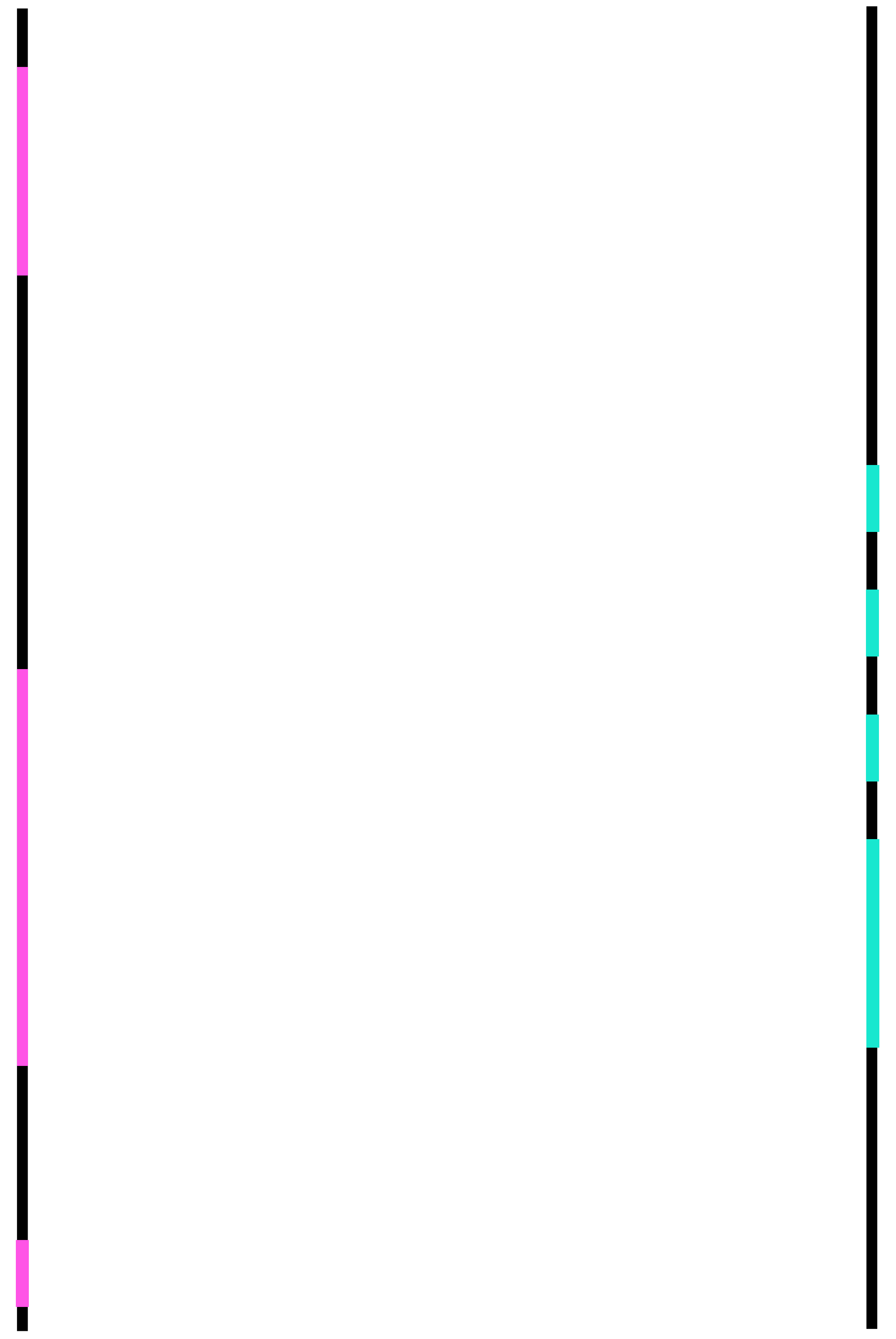
Compositional Vocabularies

Millions of Tiny Languages

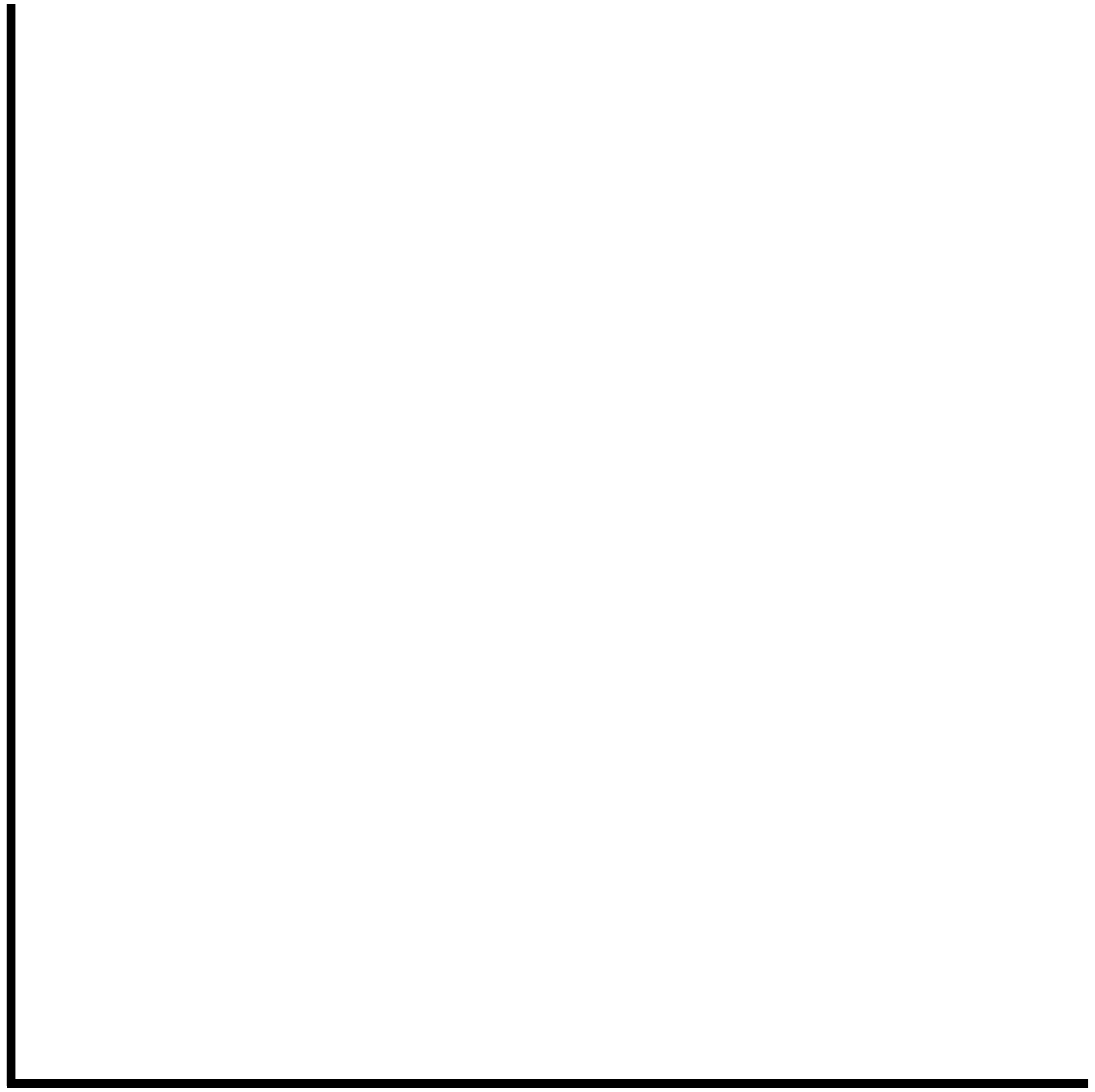
Compositional Vocabularies

Millions of Tiny Languages

Compositional Vocabularies



Compositional Vocabularies



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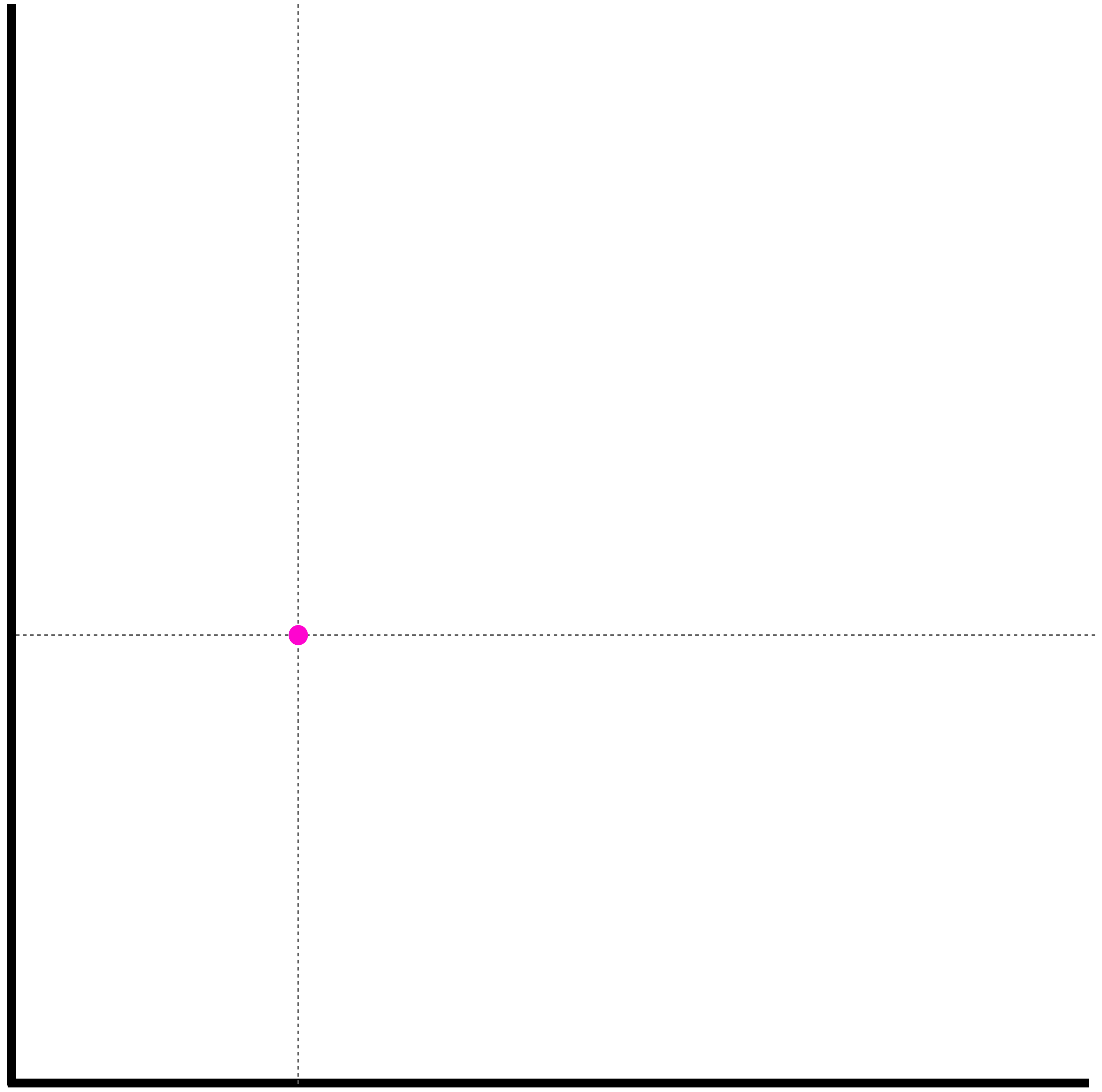
Compositional Vocabularies



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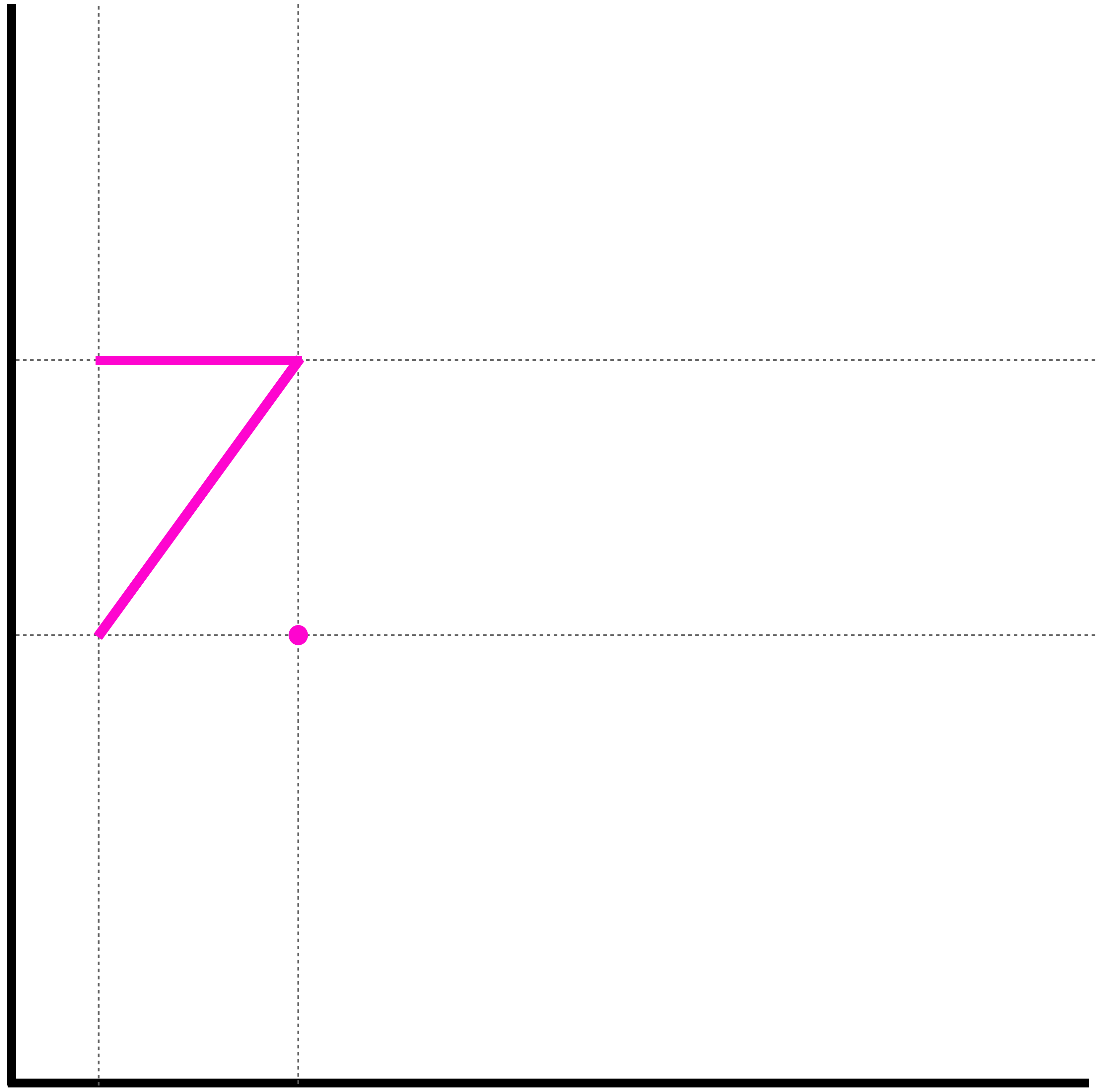
Compositional Vocabularies



Compositional Vocabularies

Millions of Tiny Languages

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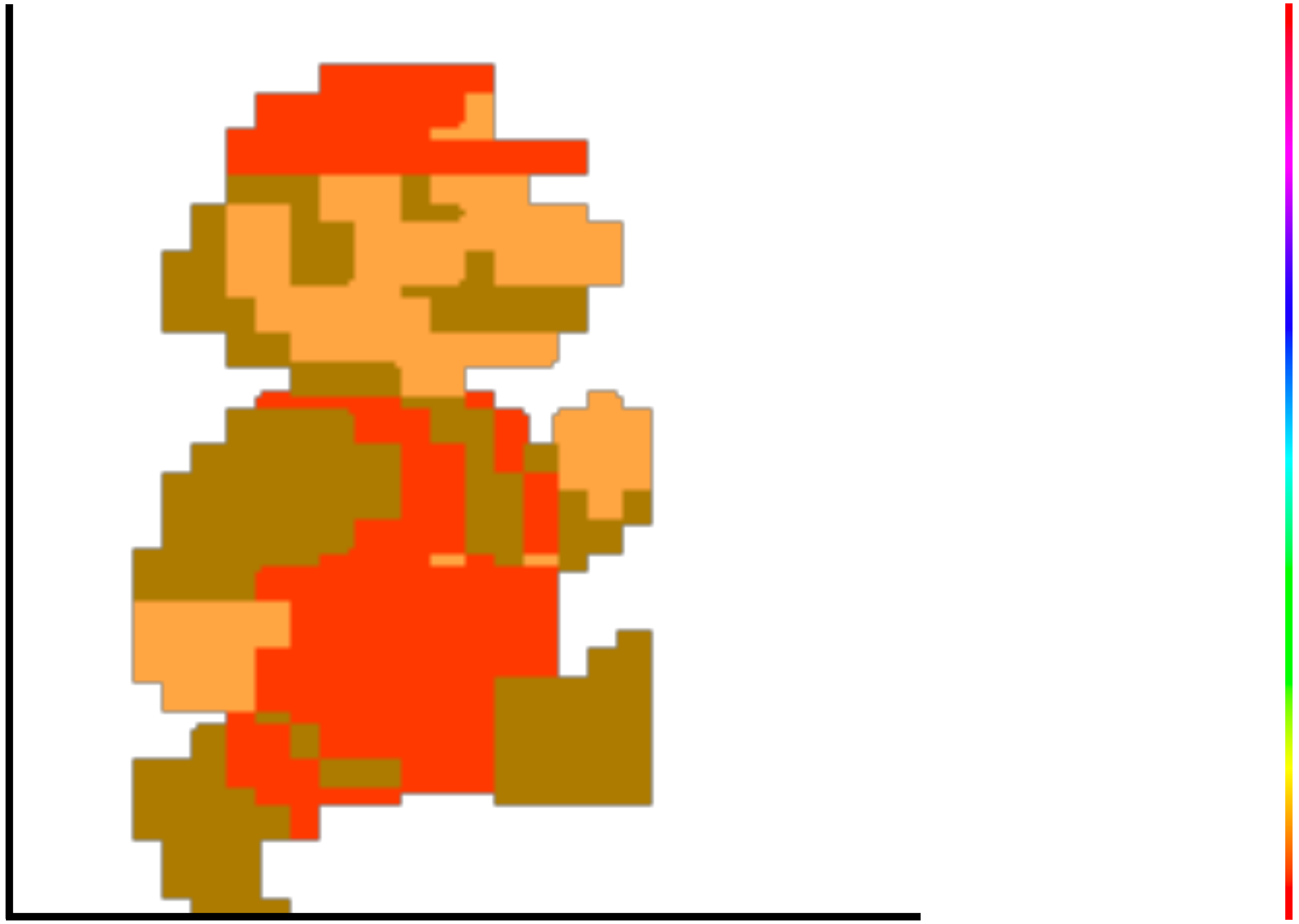
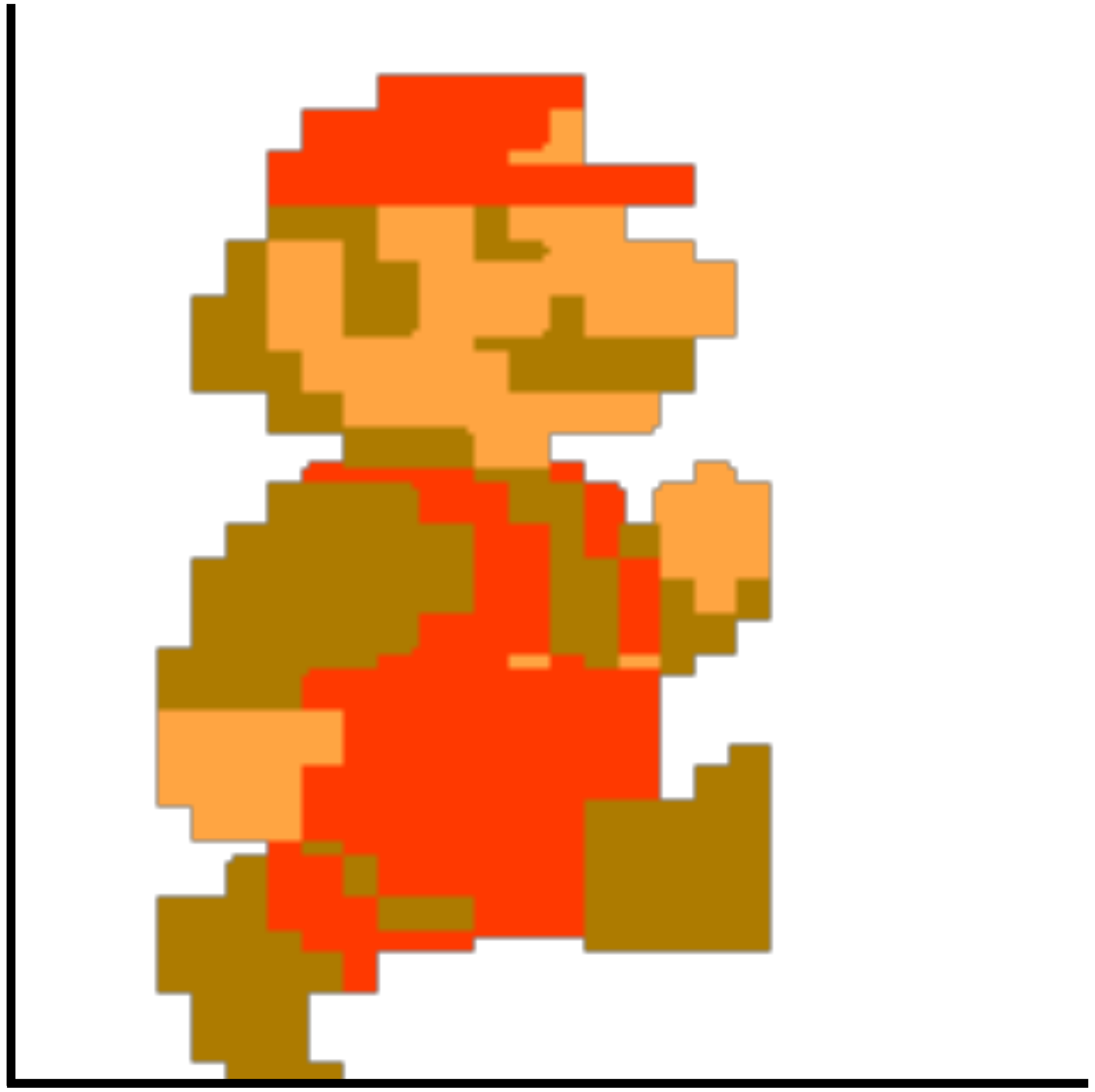
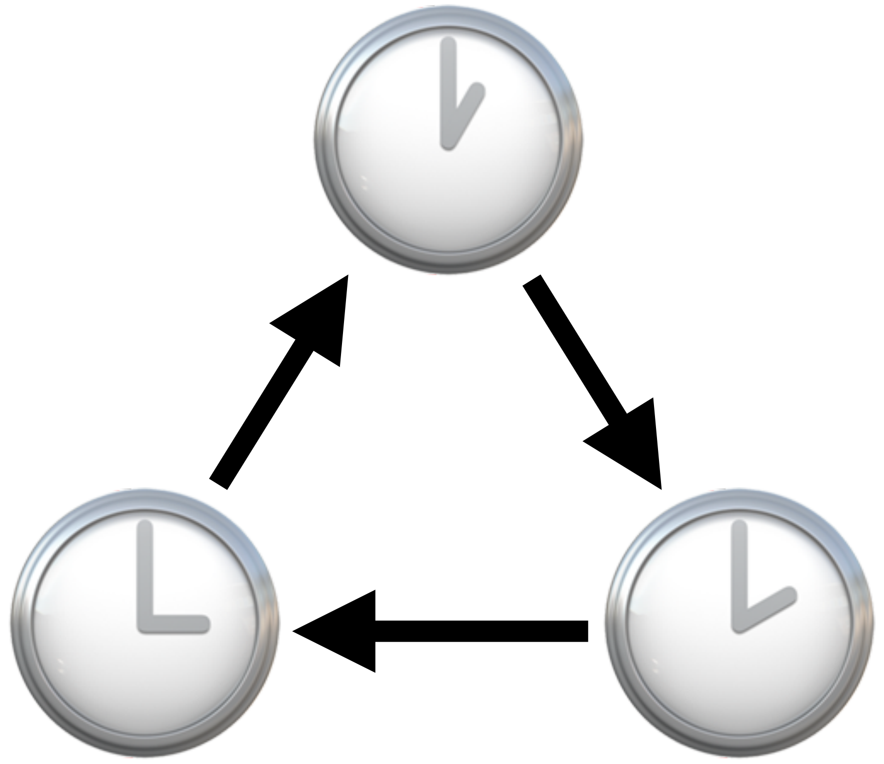
Compositional Vocabularies



Millions of Tiny Languages ⚛

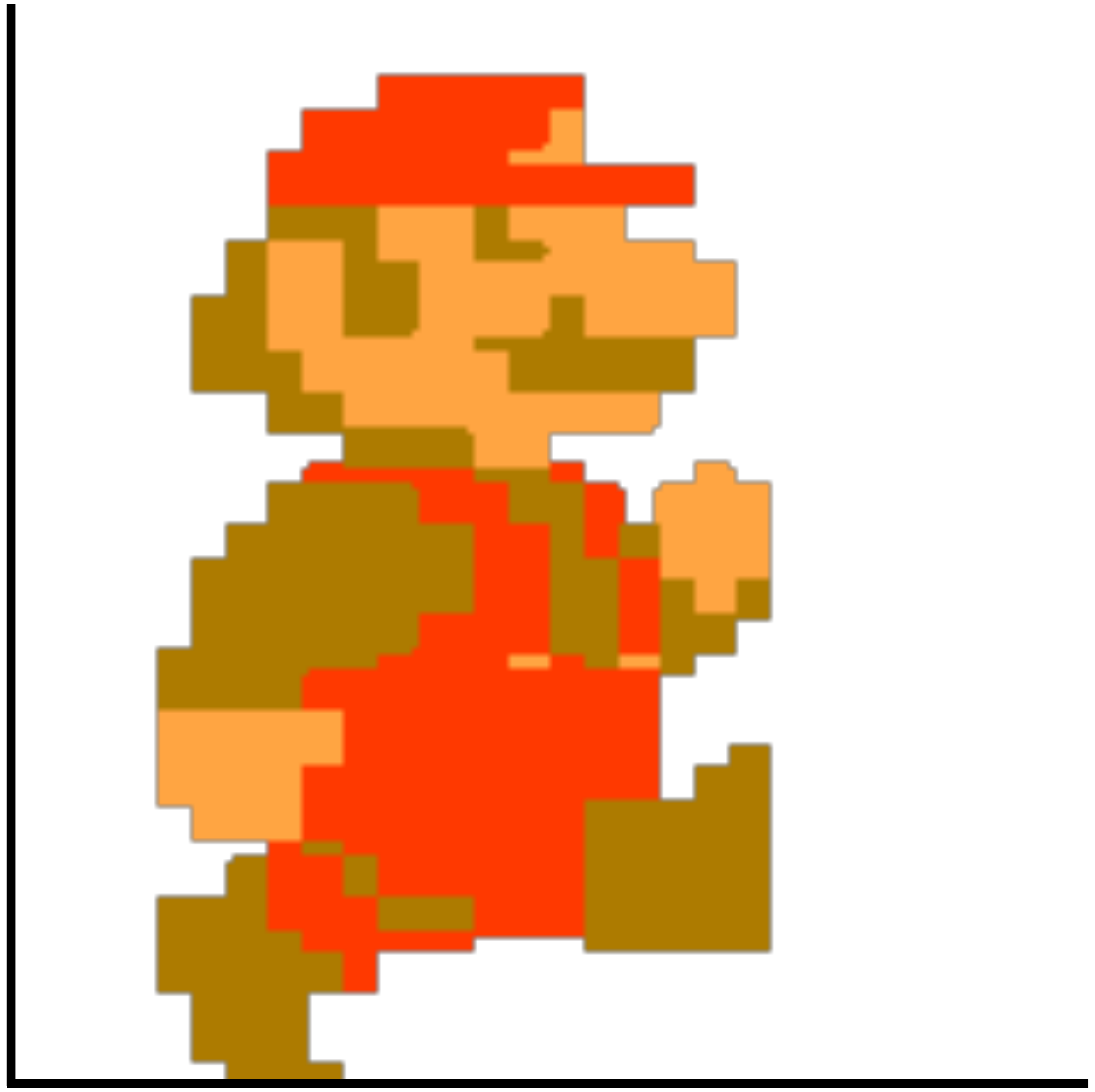
Compositional Vocabularies



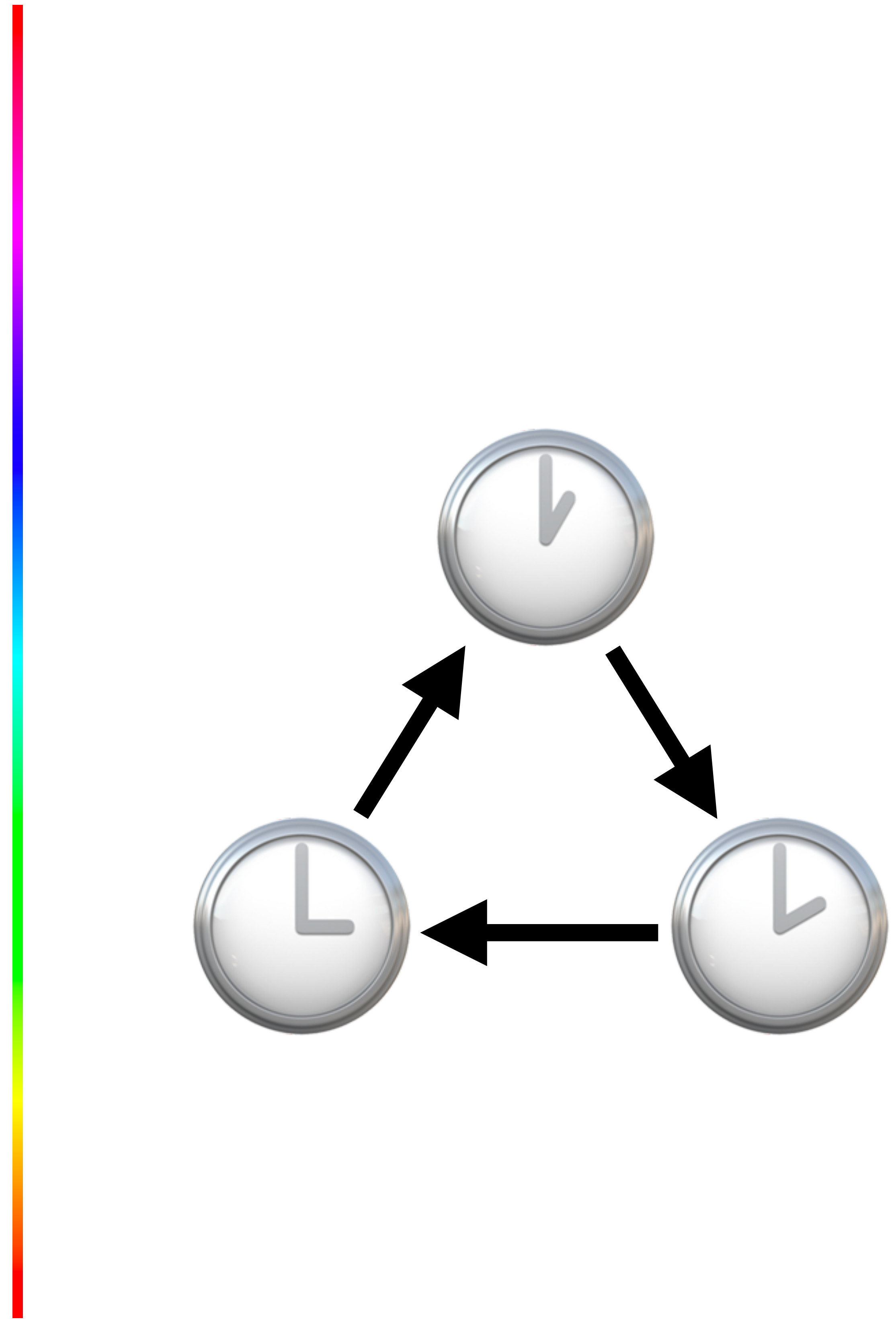


Millions of Tiny Languages ⚛

Compositional Vocabularies

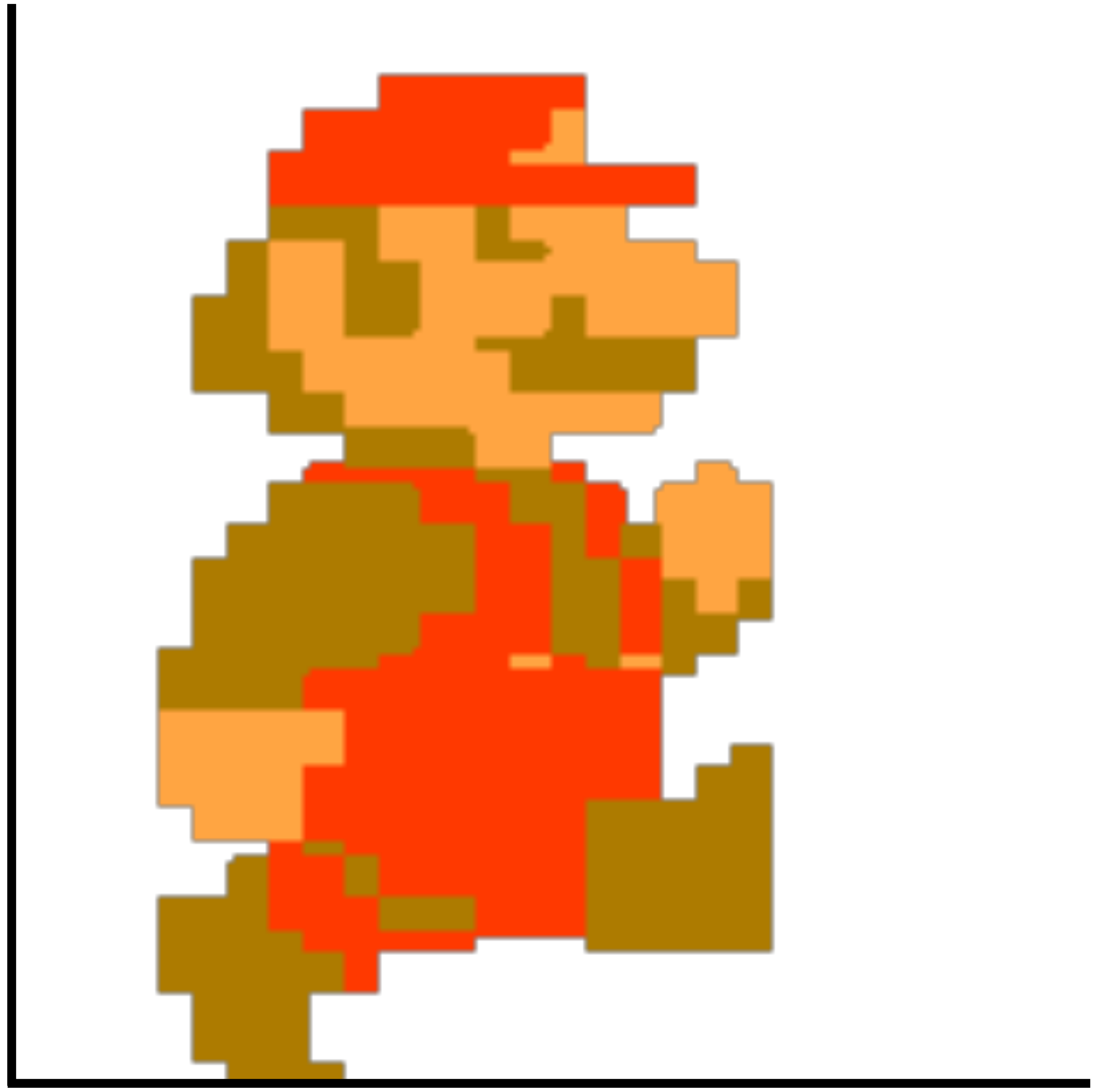


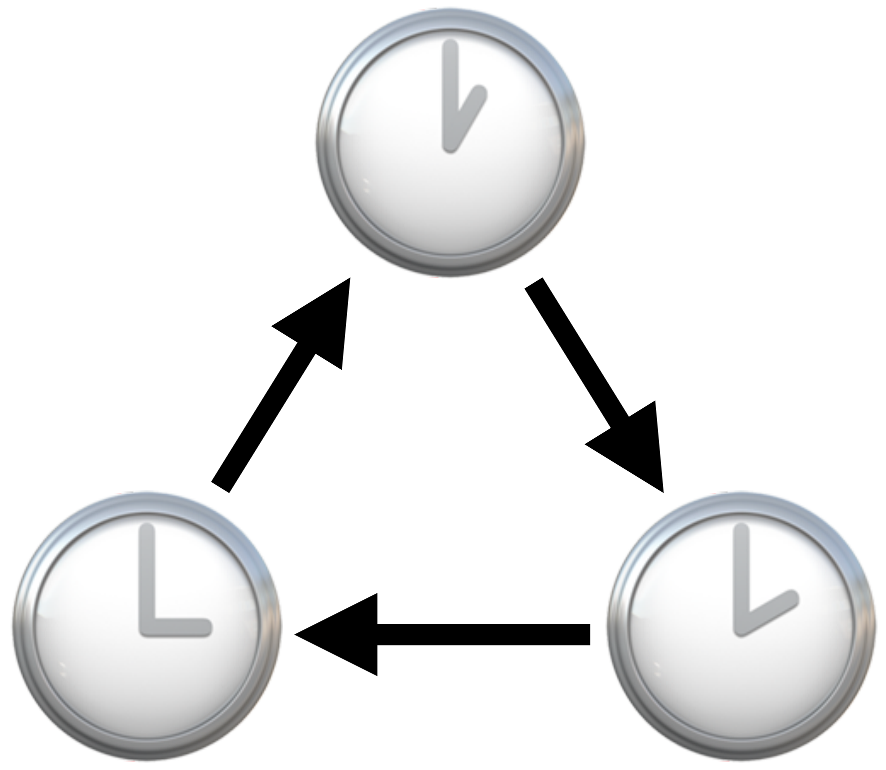
Components: 4



Millions of Tiny Languages

Compositional Vocabularies





Components: 4

Results: All of computer graphics

Millions of Tiny Languages

Interleaved Terms

Millions of Tiny Languages ⚛

Interleaved Terms

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defprotocol ImageManipulation do
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Millions of Tiny Languages

Interleaved Terms

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end
```

Millions of Tiny Languages

Interleaved Terms

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  def speak(entity, message)

  @spec listen(t, t) :: {t, String.t()}
  def listen(entity, entity)
end
```

```elixir
character
|> rotate(180)
|> speak("Why is the world upside down?")
|> scale(250)
```

✨ An AST of Your Own ✨

Building Up & Tearing Down

🧱🧨

Building Up & Tearing Down 🧱🧨

Shallow Pipes

https://hexdocs.pm/ecto/Ecto.Changeset.html#module-validations-and-constraints

Building Up & Tearing Down 🧱🧨

Shallow Pipes

- Just use the built-in AST
- What it can represent is limited
- Single, canonical implementations
- e.g. most libraries

```elixir
def changeset(user, params \\ %{}) do
  user
   |> cast(params, [:name, :email, :age])
   |> validate_required([:name, :email])
   |> validate_format(:email, ~r/@/)
   |> validate_inclusion(:age, 18..100)
   |> unique_constraint(:email)
end
```

https://hexdocs.pm/ecto/Ecto.Changeset.html#module-validations-and-constraints

Building Up & Tearing Down 🧱🧨

Shallow Pipes

https://github.com/witchcrafters/algae/blob/main/lib/algae/tree/binary_search.ex

Building Up & Tearing Down 🧱🧨

Shallow Pipes

```elixir
defmodule Algae.Tree.BinarySearch do
  alias __MODULE__, as: BST
  import Algae

  defsum do
    defdata(Empty :: none())

    defdata Node do
      node :: any()
      left :: BinarySearch.t() \\ BinarySearch.Empty.new()
      right :: BinarySearch.t() \\ BinarySearch.Empty.new()
    end
  end

  def new, do: %Empty{}
  def new(value), do: %Node{node: value}

  # ...snip...
end
```

https://github.com/witchcrafters/algae/blob/main/lib/algae/tree/binary_search.ex

Building Up & Tearing Down 🧱🧨

Shallow Pipes

```elixir
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      node :: any()
      left :: BinarySearch.t() \\ BinarySearch.Empty.new()
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    end
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  def new(value), do: %Node{node: value}

  # ...snip...
end
```

https://github.com/witchcrafters/algae/blob/main/lib/algae/tree/binary_search.ex

Building Up & Tearing Down 🧱🧨

Shallow Pipes

```
BSTree.Node.new(
  42,
  BSTree.Node.new(77),
  BSTree.Node.new(
    1234,
    BSTree.Node.new(98),
    BSTree.Node.new(32)
  )
)
```

```
defmodule Algae.Tree.BinarySearch do
  alias __MODULE__, as: BST
  import Algae

  defsum do
    defdata(Empty :: none())

    defdata Node do
      node :: any()
      left :: BinarySearch.t() \\ BinarySearch.Empty.new()
      right :: BinarySearch.t() \\ BinarySearch.Empty.new()
    end
  end

  def new, do: %Empty{}
  def new(value), do: %Node{node: value}

  # ...snip...
end
```

https://github.com/witchcrafters/algae/blob/main/lib/algae/tree/binary_search.ex

Building Up & Tearing Down 🧱🧨

Shallow Pipes

```elixir
defmodule Algae.Tree.BinarySearch do
  alias __MODULE__, as: BST
  import Algae

  defsum do
    defdata(Empty :: none())

    defdata Node do
      node :: any()
      left :: BinarySearch.t() \\ BinarySearch.Empty.new()
      right :: BinarySearch.t() \\ BinarySearch.Empty.new()
    end
  end

  def new, do: %Empty{}
  def new(value), do: %Node{node: value}

  # ...snip...
end
```

```elixir
BSTree.Node.new(
  42,
  BSTree.Node.new(77),
  BSTree.Node.new(
    1234,
    BSTree.Node.new(98),
    BSTree.Node.new(32)
  )
)
```

```elixir
%Algae.Tree.BinarySearch.Node{
  node: 42,
  left: %Algae.Tree.BinarySearch.Node{
    node:  77,
    left:  %Algae.Tree.BinarySearch.Empty{},
    right: %Algae.Tree.BinarySearch.Empty{}
  },
  right: %Algae.Tree.BinarySearch.Node{
    node:  1234,
    left:  %Algae.Tree.BinarySearch.Node{
      node:  98,
      left:  %Algae.Tree.BinarySearch.Empty{},
      right: %Algae.Tree.BinarySearch.Empty{}
    },
    right: %Algae.Tree.BinarySearch.Node{
      node:  32,
      left:  %Algae.Tree.BinarySearch.Empty{},
      right: %Algae.Tree.BinarySearch.Empty{}
    }
  }
}
```

https://github.com/witchcrafters/algae/blob/main/lib/algae/tree/binary_search.ex

Building Up & Tearing Down

Whatever You Want It To Be

- Natural Language
- GUI Metaphor
- Application Domain
- Library / Framework
- Elixir Language
- Elixir AST
- BEAM bytecode
- Kernel syscalls
- x86 / ARM / RISC-V
- Binary
- Physics
- Mathematics

Building Up & Tearing Down

Whatever You Want It To Be

There is ***nothing sacred***
about Elixir's AST;
it's just ***well suited***
for its ecological niche

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- GUI Metaphor
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Building Up & Tearing Down 🧱🧨

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There is ***nothing sacred***
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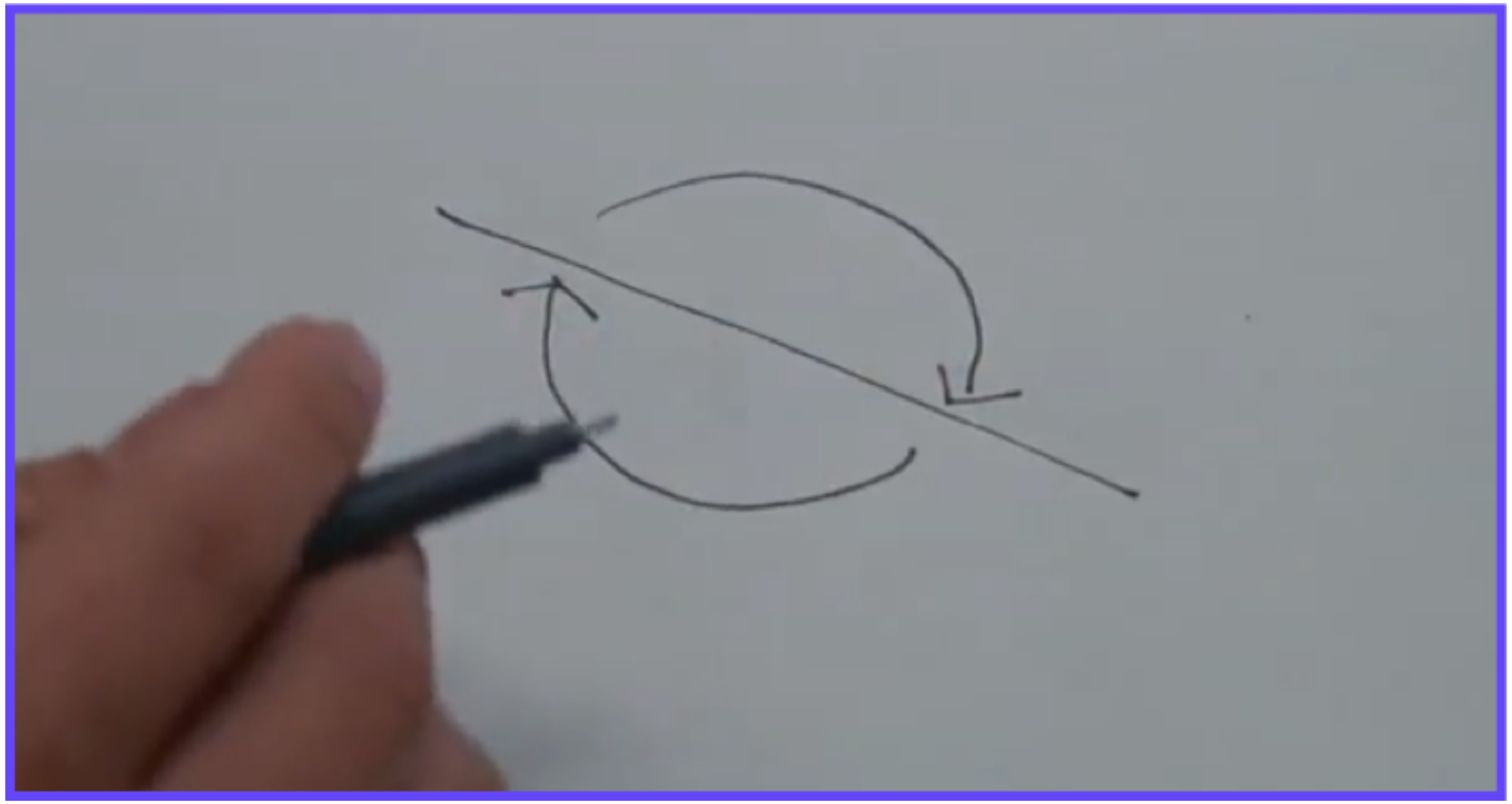
Building Up & Tearing Down 🧱🧨

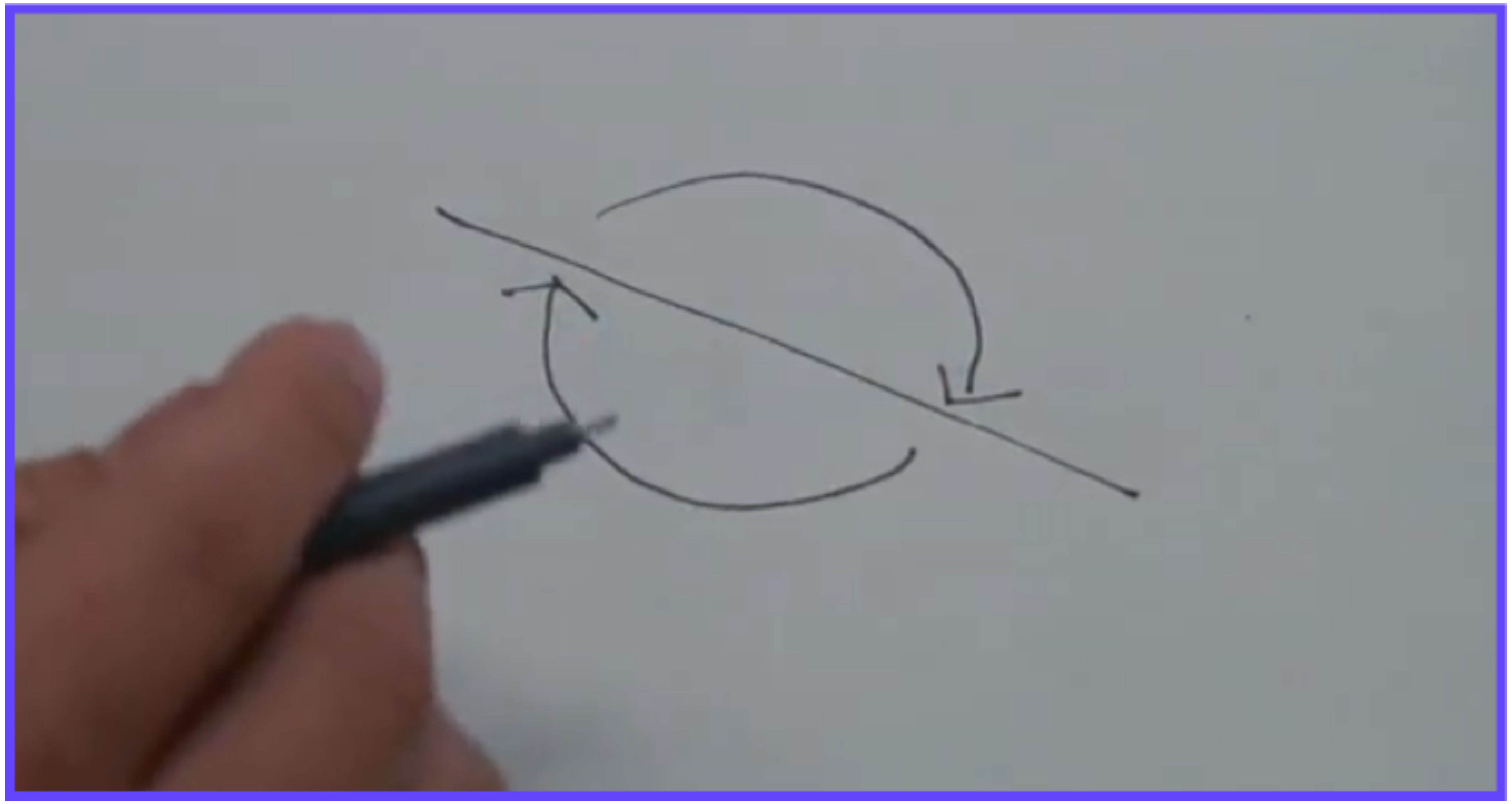
Invocation & Rewriting



Building Up & Tearing Down 🧱🧨

Invocation & Rewriting

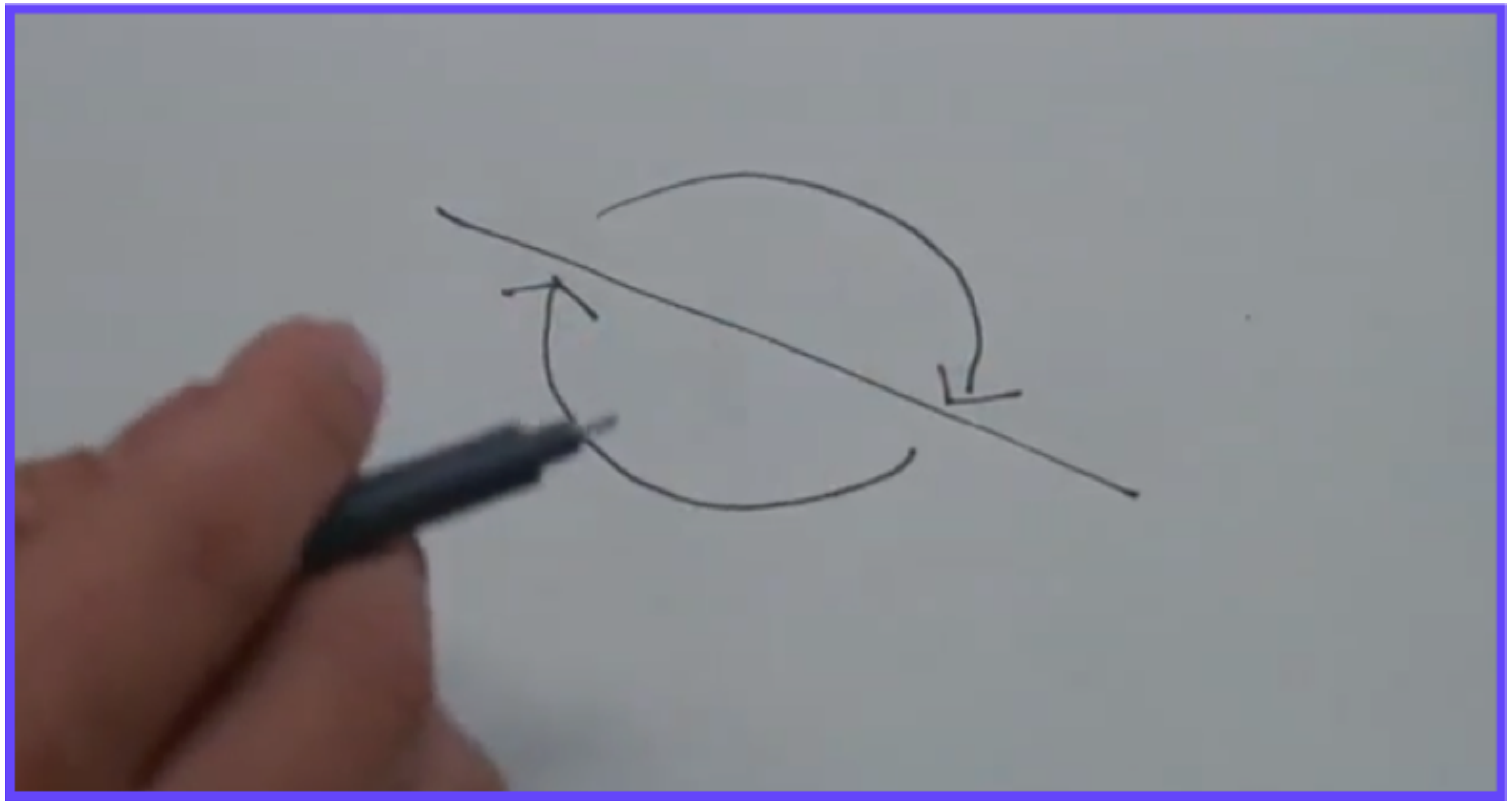
1. Build a game plan



Building Up & Tearing Down 🧱🧨

Invocation & Rewriting

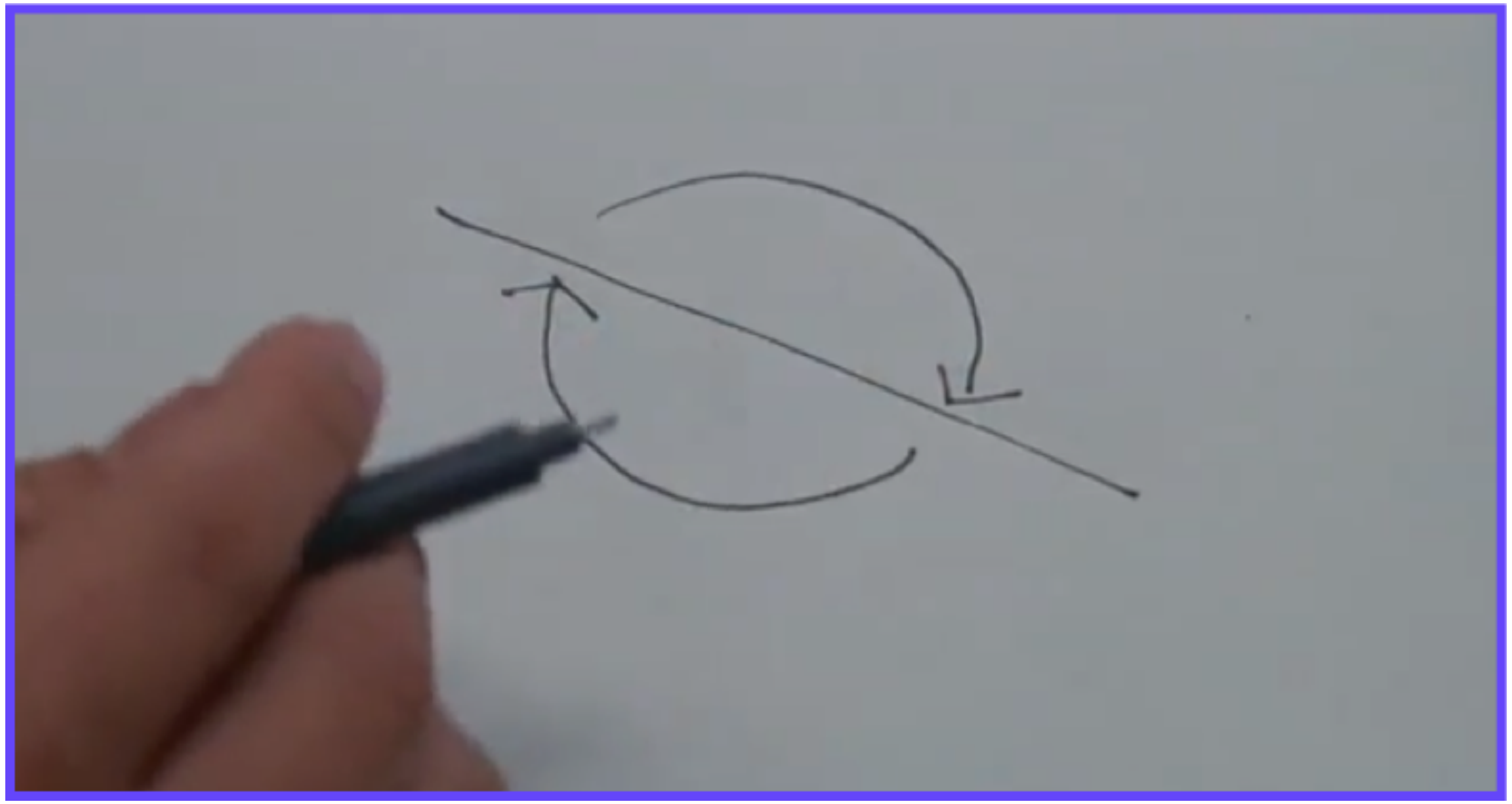
1. Build a game plan
2. Transform (optional)



Building Up & Tearing Down 🧱🧨

Invocation & Rewriting

1. Build a game plan
2. Transform (optional)
3. Tear down



Building Up & Tearing Down 🧱🧨

Connectives

Building Up & Tearing Down 🧱🧨

Connectives

```
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
```

Building Up & Tearing Down 🧱🧨

Connectives

```
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
```

Building Up & Tearing Down 🧱🧨

Connectives

```elixir
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
```

```elixir
[
  %GoNorth{mover: :dog, distance: 2},
  %Wait{seconds: 2},
  %Text.Capslock{on: true},
  %Say{speaker: :dog, text: "woof"},
  %Wait{seconds: 10}
  %Say{speaker: :dog, text: "bark bark"},
  %Text.Capslock{on: false},
  %GoWest{mover: :dog, distance: 7},
  %Wait{seconds: 2}
]
```

Building Up & Tearing Down 🧱🧨

Connectives

```elixir
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
```

```elixir
[
  %GoNorth{mover: :dog, distance: 2},
  %Wait{seconds: 2},
  %Text.Capslock{on: true},
  %Say{speaker: :dog, text: "woof"},
  %Wait{seconds: 10}
  %Say{speaker: :dog, text: "bark bark"},
  %Text.Capslock{on: false},
  %GoWest{mover: :dog, distance: 7},
  %Wait{seconds: 2}
]
```

Building Up & Tearing Down

Connectives

```elixir
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
```

```elixir
[
  %GoNorth{mover: :dog, distance: 2},
  %Wait{seconds: 2},
  %Text.Capslock{on: true},
  %Say{speaker: :dog, text: "woof"},
  %Wait{seconds: 10}
  %Say{speaker: :dog, text: "bark bark"},
  %Text.Capslock{on: false},
  %GoWest{mover: :dog, distance: 7},
  %Wait{seconds: 2}
]
```

```elixir
%GoNorth{
  mover: :dog,
  distance: 2,
  then: %Wait{
    seconds: 2,
    then: %Text.WithCaps{
      do: %Say{
            speaker: :dog,
            text: "woof",
            then: %Wait{
              seconds: 10,
              then: %Say{
                speaker: :dog,
                text: "bark bark"
              }
            }
          },
      then: %GoWest{
        mover: :dog,
        distance: 7,
        then: %Wait{seconds: 2}
      }
    }
  }
}
```

Building Up & Tearing Down 🧱🧨

Connectives

```
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
```

```
[
  %GoNorth{mover: :dog, distance: 2},
  %Wait{seconds: 2},
  %Text.Capslock{on: true},
  %Say{speaker: :dog, text: "woof"},
  %Wait{seconds: 10}
  %Say{speaker: :dog, text: "bark bark"},
  %Text.Capslock{on: false},
  %GoWest{mover: :dog, distance: 7},
  %Wait{seconds: 2}
]
```

```
%GoNorth{
  mover: :dog,
  distance: 2,
  then: %Wait{
    seconds: 2,
    then: %Text.WithCaps{
      do: %Say{
        speaker: :dog,
        text: "woof",
        then: %Wait{
          seconds: 10,
          then: %Say{
            speaker: :dog,
            text: "bark bark"
          }
        }
      }
      ,
      then: %GoWest{
        mover: :dog,
        distance: 7,
        then: %Wait{seconds: 2}
      }
    }
  }
}
```

Building Up & Tearing Down 🧱🧨

GenEffect

Building Up & Tearing Down 🧱🧨

GenEffect

```elixir
defmodule Time do
  use GenEffect
  # ...
  def handle_effect(%Wait{seconds: seconds}), do: Process.sleep(seconds)
end
```

Building Up & Tearing Down 🧱🧨

GenEffect

```elixir
defmodule Time do
  use GenEffect
  # ...
  def handle_effect(%Wait{seconds: seconds}), do: Process.sleep(seconds)
end
```

```elixir
defmodule Speaking do
  use GenEffect
  # ...
  def handle_effect(%Say{speaker: who, text: msg}), do: IO.puts("#{who} says #{msg}")
end
```

Building Up & Tearing Down 🧱🧨

GenEffect

```elixir
defmodule Time do
  use GenEffect
  # ...
  def handle_effect(%Wait{seconds: seconds}), do: Process.sleep(seconds)
end
```

```elixir
defmodule Speaking do
  use GenEffect
  # ...
  def handle_effect(%Say{speaker: who, text: msg}), do: IO.puts("#{who} says #{msg}")
end
```

```elixir
defmodule Text do
  use GenEffect
  # ...
  def handle_effect(%Capslock{on: true}, state) do
    IO.ANSI.capslock()
    %{state | caps: true}
  end
end
```

Building Up & Tearing Down 🧱🧨

Interpreter

Building Up & Tearing Down 🧱🧨

Interpreter

```
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
|> run(Text)
|> run(Time)
|> run(Speaking)
```

Building Up & Tearing Down 🧱🧨

Interpreter

```
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
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    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
|> run(Text)
|> run(Time)
|> run(Speaking)
```

Building Up & Tearing Down 🧱🧨

Interpreter

```
with_npc :dog do
  move(:north, 2)
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  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
|> run(Text)
|> run(Time)
|> run(Speaking)
```

Building Up & Tearing Down 🧱🧨

Interpreter

```
# ...
IO.ANSI.capslock()
Agent.set(pid, fn state -> %{state | caps: true} end)
IO.puts("woof")
Process.sleep(10)
IO.ANSI.capslock()
Agent.set(pid, fn state -> %{state | caps: false} end)
# ...
```

```
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
|> run(Text)
|> run(Time)
|> run(Speaking)
```

Building Up & Tearing Down 🧱🧨

Interpreter

```elixir
# ...
IO.ANSI.capslock()
Agent.set(pid, fn state -> %{state | caps: true} end)
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IO.ANSI.capslock()
Agent.set(pid, fn state -> %{state | caps: false} end)
# ...
```

```elixir
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

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    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
|> run(Text)
|> run(Time)
|> run(Speaking)
```

Why not use a protocol?

Canonicity!

Domain & Denotation

Standard Vocabularies

🔠

Standard Vocabularies 🔠

What Is Common?

```
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
```

```
defprotocol GameActions do
  @type direction :: :north | :south | :east | :west

  @spec move(t, direction(), non_neg_number()) :: t
  def move(entity, direction, paces)

  @spec speak(t, String.t()) :: t
  def speak(entity, message)

  @spec listen(t, t) :: {t, String.t()}
  def listen(entity, entity)
end
```

```
defprotocol ImageManipulation do
  @spec rotate(t, non_neg_integer()) :: t
  def rotate(image, degrees)

  @spec scale(t, integer()) :: t
  def scale(image, percentage)

  @spec translate(t, integer(), non_neg_integer()) :: t
  def translate(image, degrees, distance_in_pixels)
end
```

Standard Vocabularies 🔠

What Is Common?

Movement!

```elixir
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
```

```elixir
defprotocol GameActions do
  @type direction :: :north | :south | :east | :west

  @spec move(t, direction(), non_neg_number()) :: t
  def move(entity, direction, paces)

  @spec speak(t, String.t()) :: t
  def speak(entity, message)

  @spec listen(t, t) :: {t, String.t()}
  def listen(entity, entity)
end
```

```elixir
defprotocol ImageManipulation do
  @spec rotate(t, non_neg_integer()) :: t
  def rotate(image, degrees)

  @spec scale(t, integer()) :: t
  def scale(image, percentage)

  @spec translate(t, integer(), non_neg_integer()) :: t
  def translate(image, degrees, distance_in_pixels)
end
```

Standard Vocabularies 🔤

One Level Down

Standard Vocabularies 🔠

One Level Down

```
defprotocol GraphRouting do
  def adjacentcies(graph, node)
  def move(graph, node, adjacency)
end
```

```
defprotocol Geometric do
  def scale(object, factor)
  def translate(object, angle, distance)
  def rotate(object, angle)
  def shear(object, delta_v, delta_h)
end
```

Standard Vocabularies 🔤

One Level Down

```elixir
defprotocol GraphRouting do
  def adjacentcies(graph, node)
  def move(graph, node, adjacency)
end
```

```elixir
defprotocol PartialOrder do
  def compare(a, b)
end
```

```elixir
defprotocol Geometric do
  def scale(object, factor)
  def translate(object, angle, distance)
  def rotate(object, angle)
  def shear(object, delta_v, delta_h)
end
```

```elixir
defprotocol Setlike do
  def union(a, b)
  def intersect(a, b)
end
```

Standard Vocabularies 🔠

What's Important About Laws?

```elixir
defprotocol PartialOrder do
  def compare(a, b)
end
```

Standard Vocabularies 🔠

What's Important About Laws?

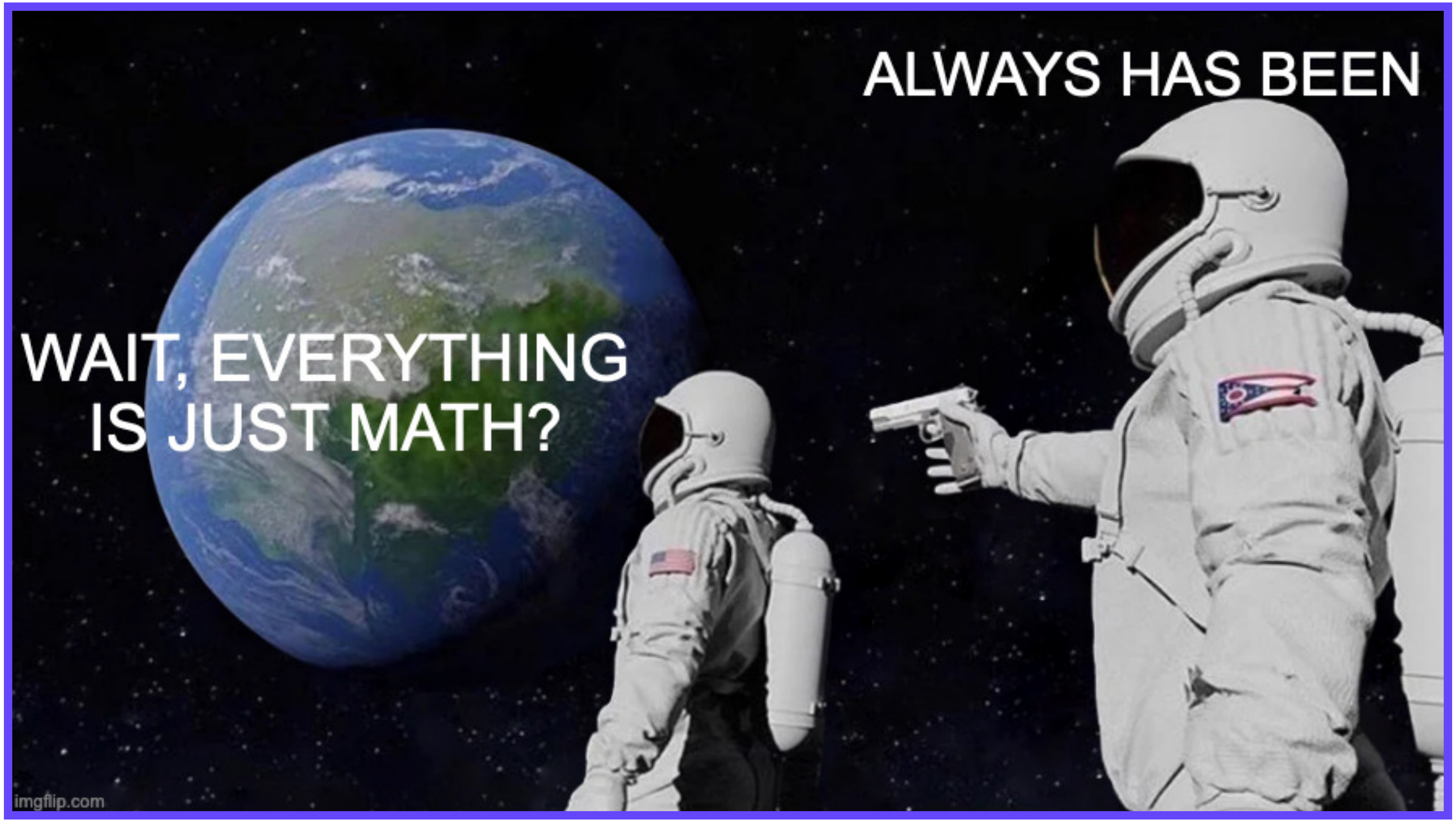
```
defprotocol PartialOrder do
  def compare(a, b)
end
```

```
# a relates to itself
a <= a

# equal elements don't preceed themselves
if a <= b && b <= a, then: a == b

# transitive
if a <= b && b <= c, then: a <= c
```

Consistent in all contexts

Standard Vocabularies 🔤

Denotative Redux



Standard Vocabularies 🔠

Denotative Redux

Standard Vocabularies 🔤

Denotative Redux

We are only drawing a most important distinction — between ***discovering something and inventing something***. But mathematicians make the most important discoveries.

– Alan Turing, via Wittgenstein's Lectures on the Foundations of Mathematics

Standard Vocabularies 🔤

Safety First

Purify Your Effects

🦺⛑️🪄

Purify Your Effects 🦺⛑️🪄

Have no truck with the
grubby compromises
of imperative programming

— Simon Peyton Jones

Purify Your Effects 🦺⛑️🪄

Tools Down

Purify Your Effects 🦺⛑️🪄

Tools Down

Elixir is surprisingly ***imperative,***
yet gives you ***all the tools*** of equational reasoning
...so let's use them!

Purify Your Effects 🦺⛑️🪄

Description vs Invocation

Description vs Invocation

Impure functions produce ***side effects***
Pure functions manipulate ***data***

Side effects → ***managed*** effects

Purify Your Effects 🦺⛑️🪄

Description vs Invocation

Impure functions produce ***side effects***
Pure functions manipulate ***data***

Side effects → ***managed*** effects

`function`

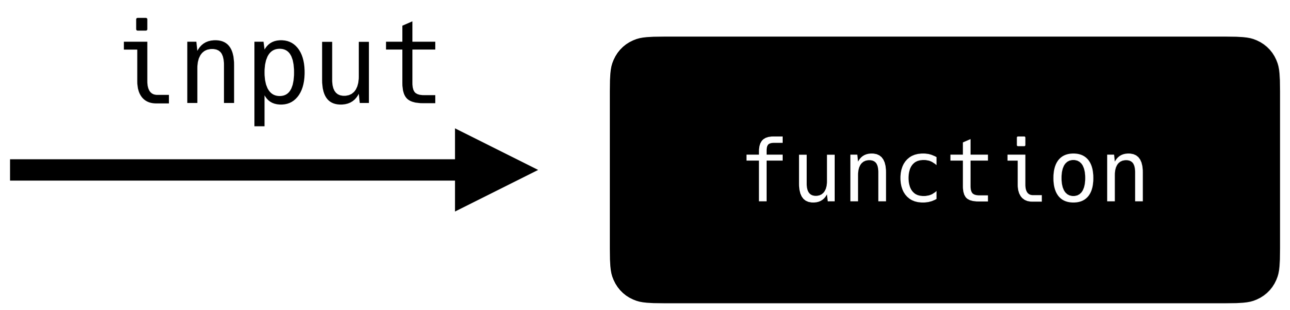
Purify Your Effects 🦺⛑️🪄

Description vs Invocation

Impure functions produce ***side effects***

Pure functions manipulate ***data***

Side effects → ***managed*** effects

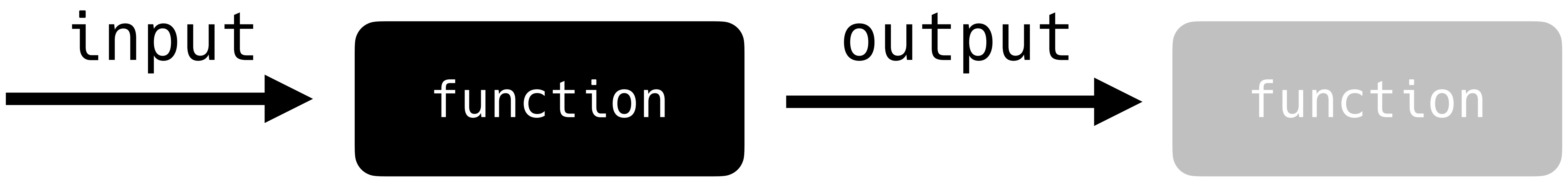


Purify Your Effects 🦺⛑️🪄

Description vs Invocation

Impure functions produce ***side effects***
Pure functions manipulate ***data***

Side effects → ***managed*** effects



Purify Your Effects 🦺⛑️🪄

Description vs Invocation

Impure functions produce ***side effects***
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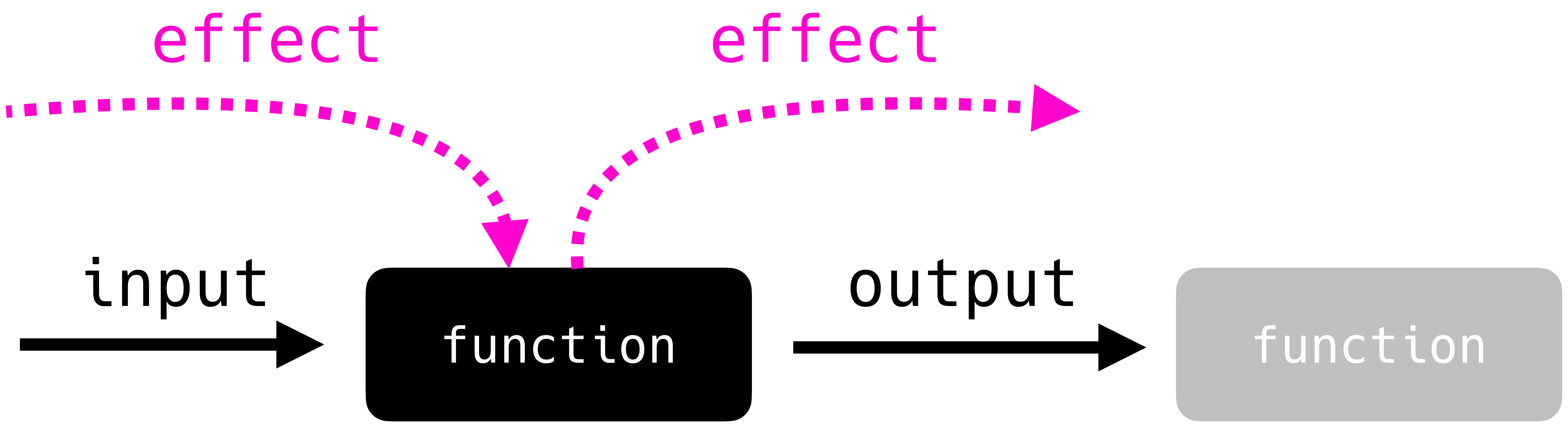
Side effects → ***managed*** effects

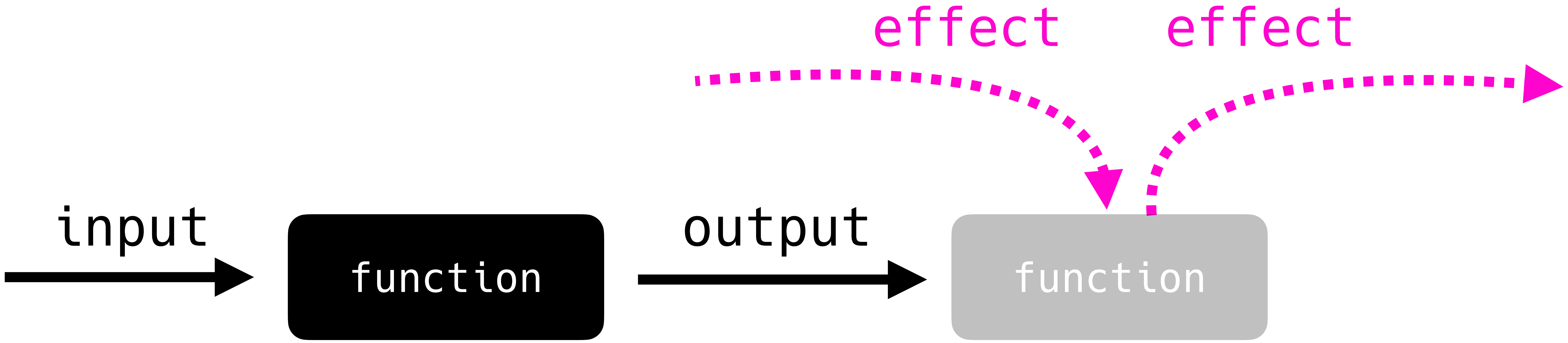


Purify Your Effects 🦺⛑️🪄

Description vs Invocation

Impure functions produce ***side effects***
Pure functions manipulate ***data***

Side effects → ***managed*** effects



Purify Your Effects 🦺⛑️🪄

4-Layer Architecture

Purify Your Effects 🦺⛑️🪄

4-Layer Architecture

Imperative

Managed Effects

Pure Functions

Data

Purify Your Effects 🦺⛑️🪄

4-Layer Architecture

💥 ***Action***

Imperative

Managed Effects

Pure Functions

Data

💡 ***Information***

Purify Your Effects 🦺⛑️🪄

4-Layer Architecture

💥 **Action** — **Unstable** 🌋

- Imperative
- Managed Effects
- Pure Functions
- Data

💡 **Information** — **Stable** 🏔️

Purify Your Effects 🦺⛑️🪄

Purified Actions

```
# ...
IO.ANSI.capslock()
Agent.set(pid, fn state -> %{state | caps: true} end)
IO.puts("woof")
Process.sleep(10)
IO.ANSI.capslock()
Agent.set(pid, fn state -> %{state | caps: false} end)
# ...
```

```
convert [Text, Time, Speaking] do
  with_npc :dog do
    move(:north, 2)
    wait(2, :seconds)

    with_caps do
      say("woof")
      wait(10, :seconds)
      say("bark bark")
    end

    move(:west, 7)
    wait(2, :seconds)
  end
end
```

Well Behaved Models

Testing Minus the Teeth

Testing Minus the Teeth 🧪

Faking Without Mocks

Testing Minus the Teeth 🧪

Faking Without Mocks

- Inspect the pure data!
- Have tests write to a list as they run
- Fake databases with maps
- Fake sending email with logs

Testing Minus the Teeth 🧪

Faking Without Mocks

- Inspect the pure data!
- Have tests write to a list as they run
- Fake databases with maps
- Fake sending email with logs

```
with_npc :dog do
  move(:north, 2)
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  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
|> run(Text)
|> run(Time)
|> run(Speaking)
```

Testing Minus the Teeth 🧪

Faking Without Mocks

- Inspect the pure data!
- Have tests write to a list as they run
- Fake databases with maps
- Fake sending email with logs

```
%GoNorth{
  mover: :dog,
  distance: 2,
  then: %Wait{
    seconds: 2,
    then: %Text.WithCaps{
      do: %Say{
            speaker: :dog,
            text: "woof",
            then: %Wait{
              seconds: 10,
              then: %Say{
                speaker: :dog,
                text: "bark bark"
              }
            }
      },
      then: %GoWest{
        mover: :dog,
        distance: 7,
        then: %Wait{seconds: 2}
      }
    }
  }
}
```

```
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
|> run(Text)
|> run(Time)
|> run(Speaking)
```

Testing Minus the Teeth 🧪

Faking Without Mocks

- Inspect the pure data!
- Have tests write to a list as they run
- Fake databases with maps
- Fake sending email with logs

```
%GoNorth{
  mover: :dog,
  distance: 2,
  then: %Wait{
    seconds: 2,
    then: %Text.WithCaps{
      do: %Say{
            speaker: :dog,
            text: "woof",
            then: %Wait{
              seconds: 10,
              then: %Say{
                speaker: :dog,
                text: "bark bark"
              }
            }
      },
      then: %GoWest{
        mover: :dog,
        distance: 7,
        then: %Wait{seconds: 2}
      }
    }
  }
}
```

```
with_npc :dog do
  move(:north, 2)
  wait(2, :seconds)

  with_caps do
    say("woof")
    wait(10, :seconds)
    say("bark bark")
  end

  move(:west, 7)
  wait(2, :seconds)
end
|> run(Text)
|> run(Time)
|> run(Speaking)
```

Control Dominator Take the Wheel

Implicit Parallelism

Implicit Parallelism 🥄

Humans are Terrible at Concurrency 😱

Implicit Parallelism 🥄

Humans are Terrible at Concurrency 😱

The main way of dealing with concurrency has been ***reduced to sequential reasoning*** [...]
it requires to cope with many possible, ***unpredictable*** behaviors of process, and the communication media

Everything is ***NOT reducible*** to sequential thinking

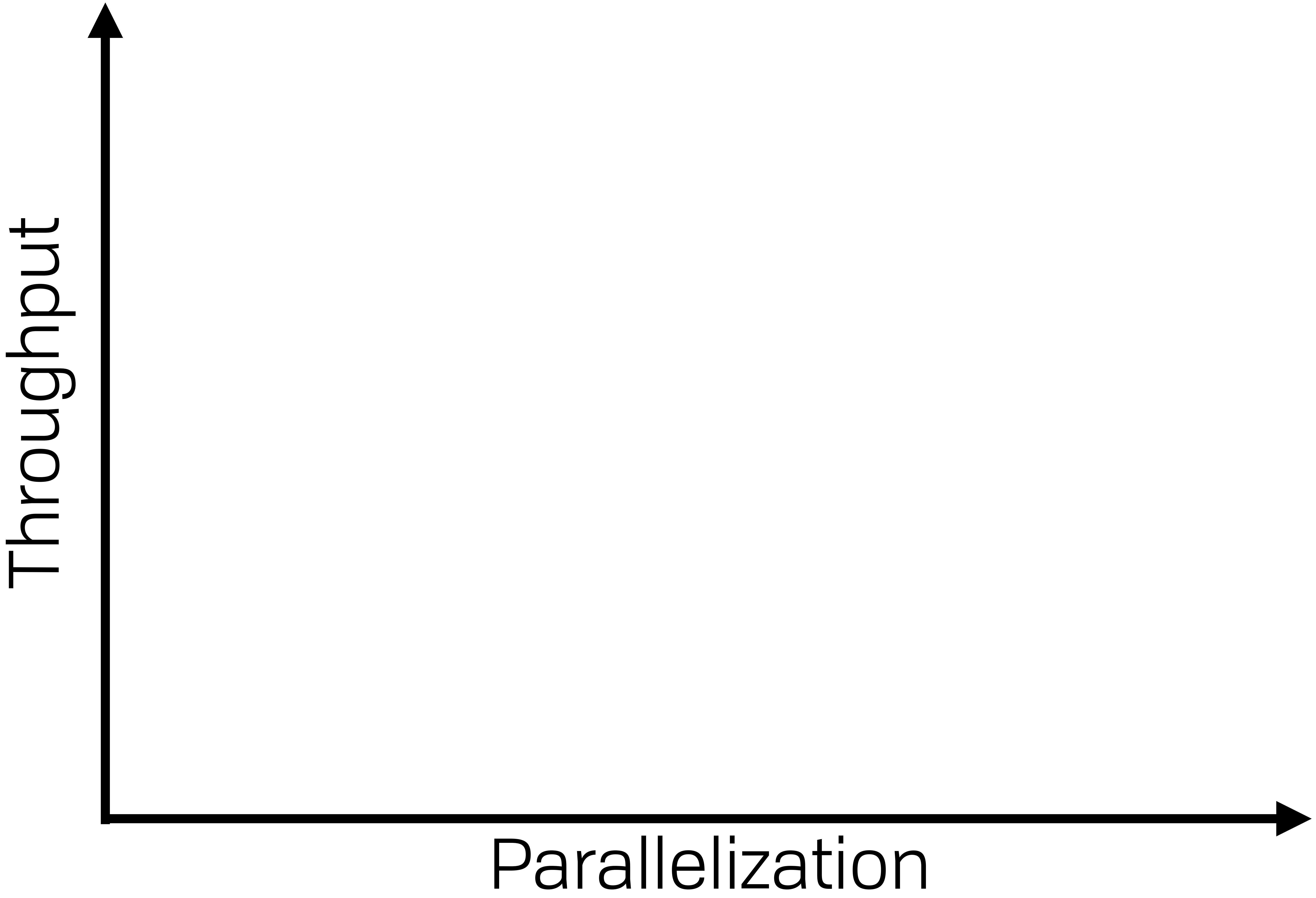
— Sergio Rajsbaum & Michel Raynal, 60 Years of Mastering Concurrency Through Sequential Thinking

Implicit Parallelism 🥄

Coordination Costs

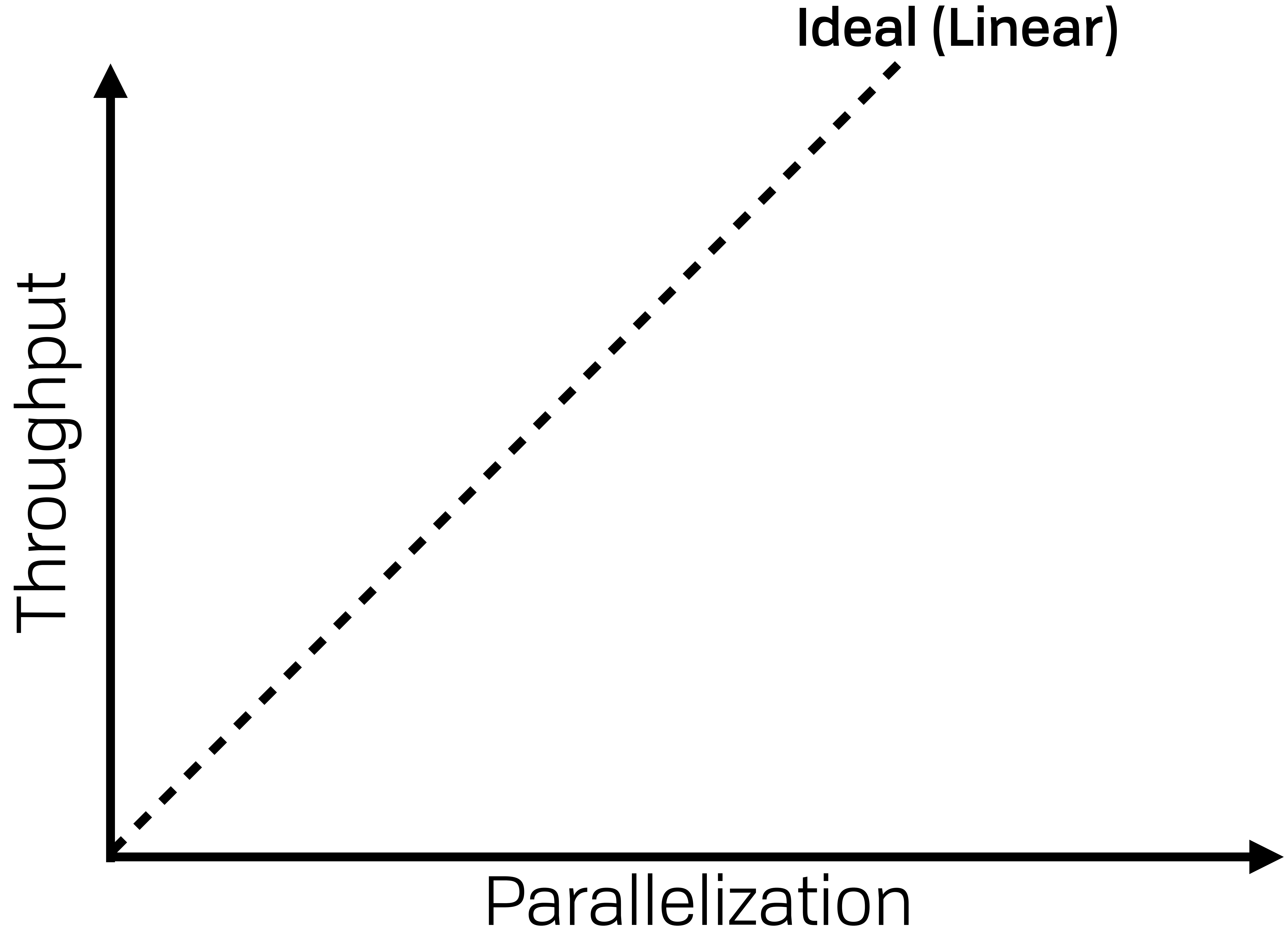
Implicit Parallelism 🥄

Coordination Costs



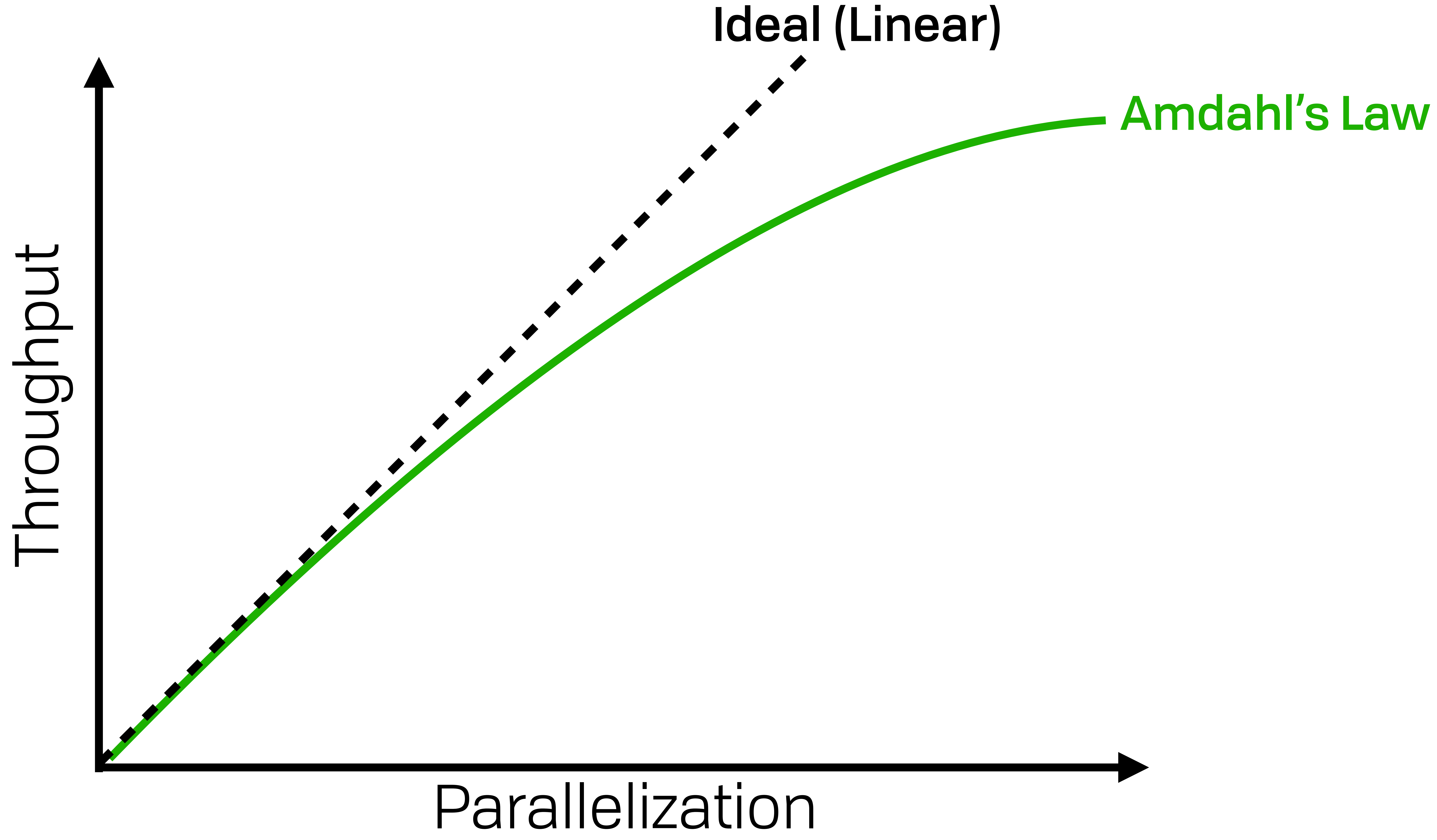
Implicit Parallelism 🥄

Coordination Costs



Implicit Parallelism 🥄

Coordination Costs



Implicit Parallelism 🥄

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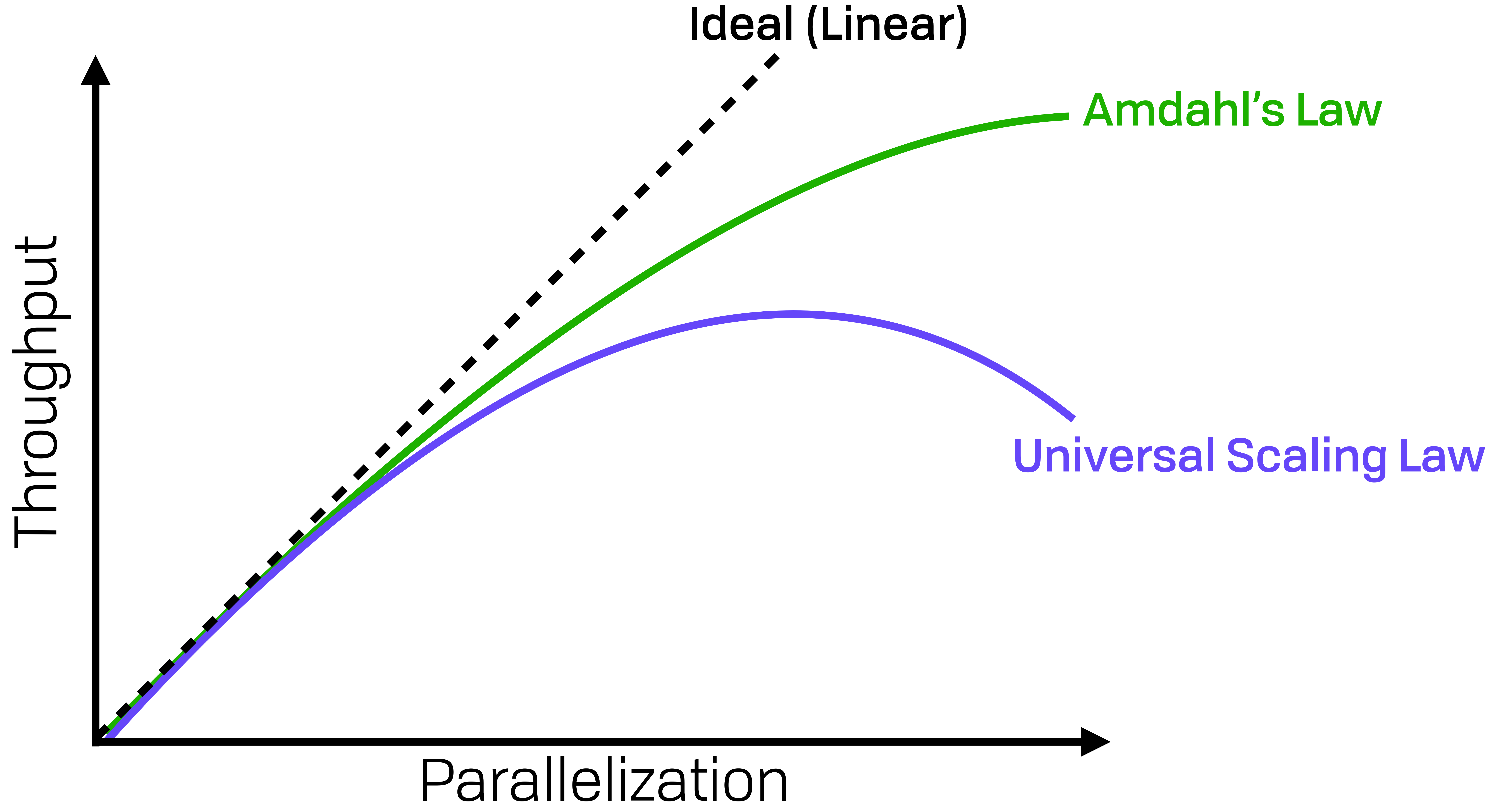

Implicit Parallelism 🥄

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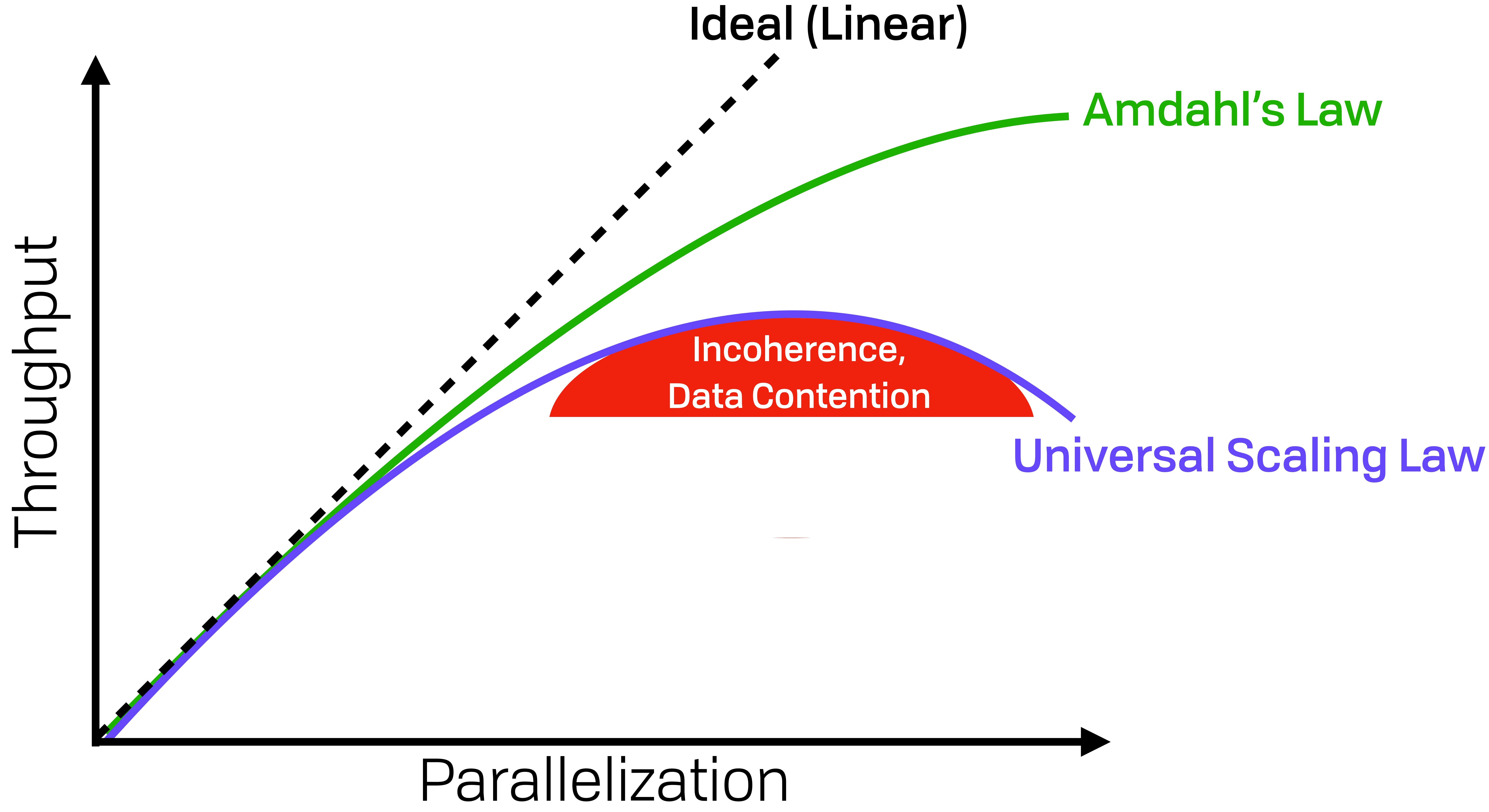

Implicit Parallelism 🥄

Confluence / Church-Rosser

Implicit Parallelism 🥄

Confluence / Church-Rosser

```
foo(bar(42), baz(97))
```

Implicit Parallelism 🥄

Confluence / Church-Rosser

```
foo(bar(42), baz(97))
```

```
y = baz(86)
x = bar(42)
foo(x, y)
```

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x = bar(42)
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Implicit Parallelism 🥄

Confluence / Church-Rosser

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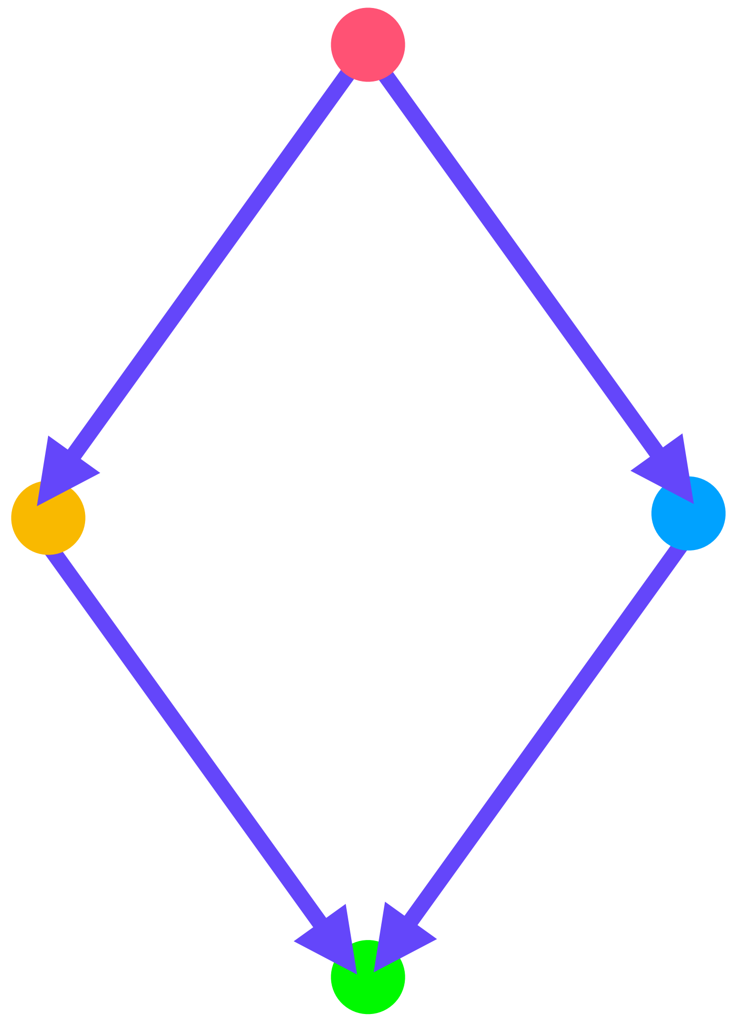

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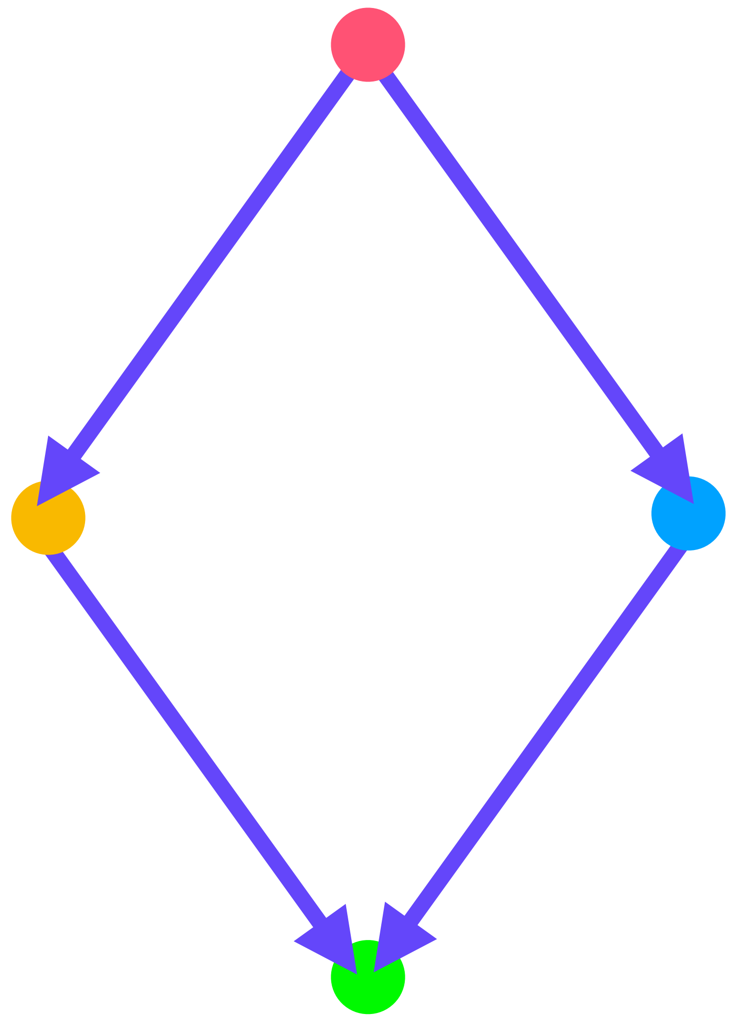

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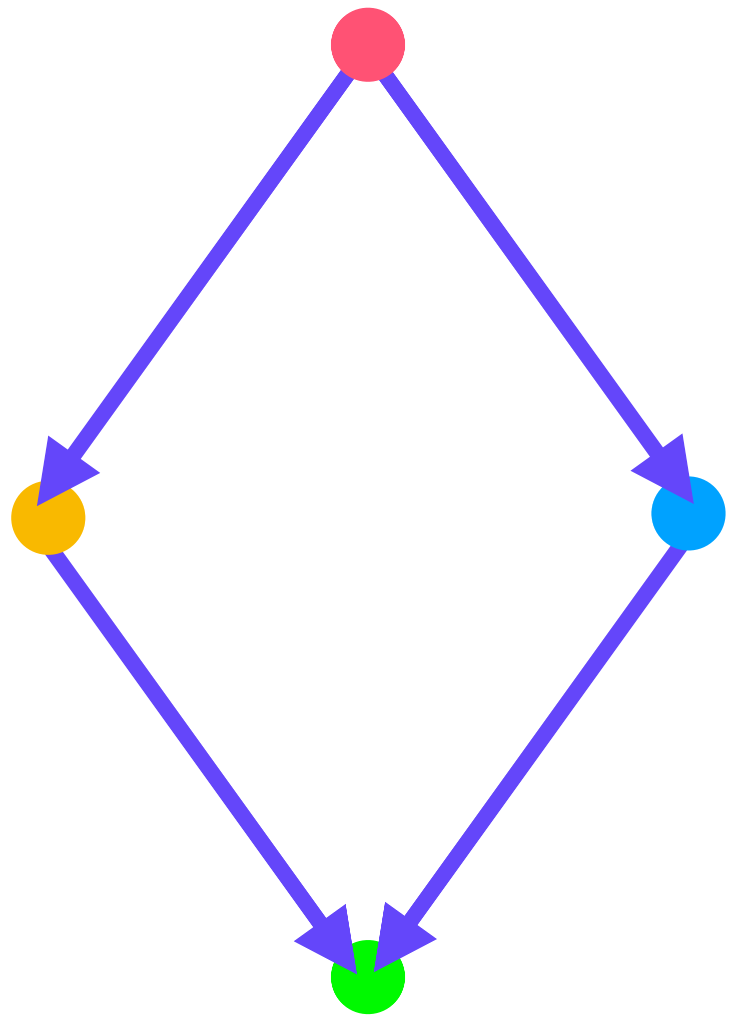

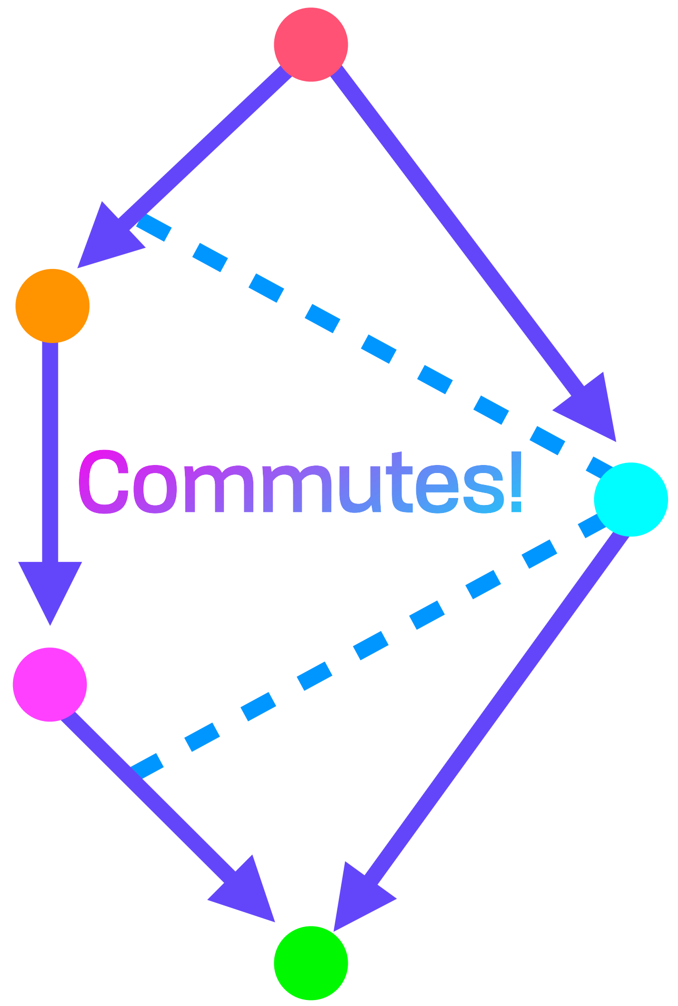

Implicit Parallelism 🥄

Confluence / Church-Rosser

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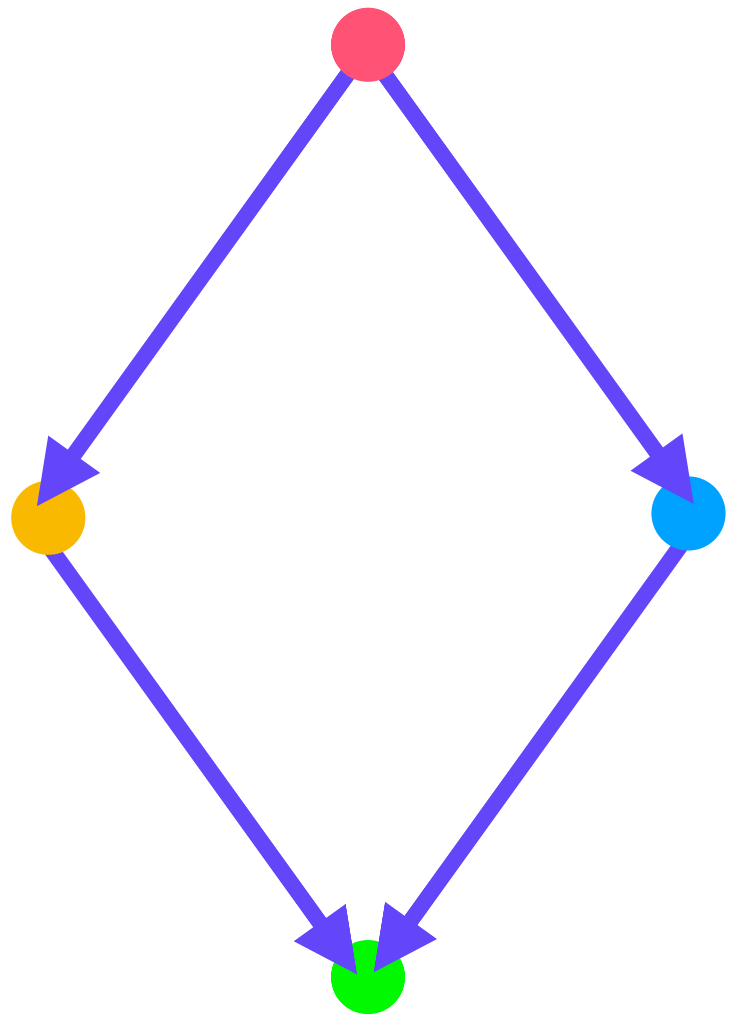

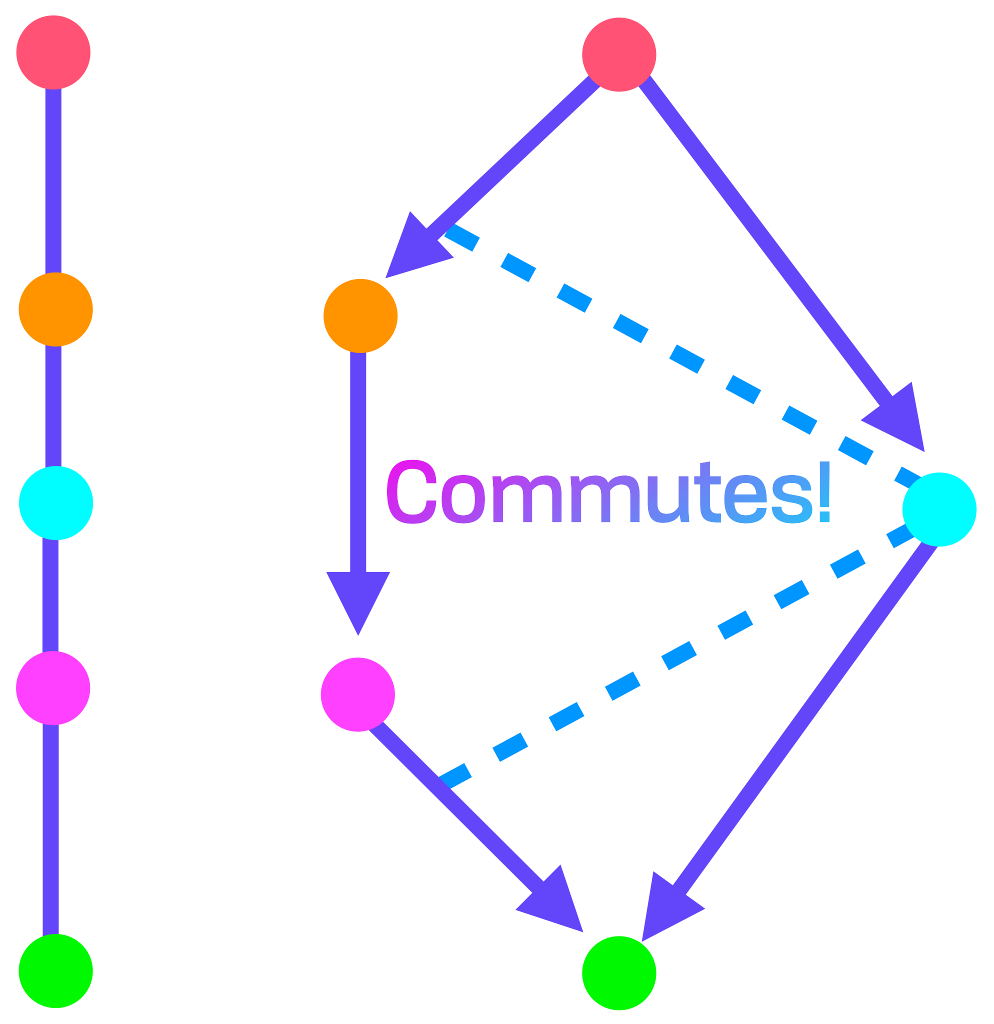

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Confluence / Church-Rosser

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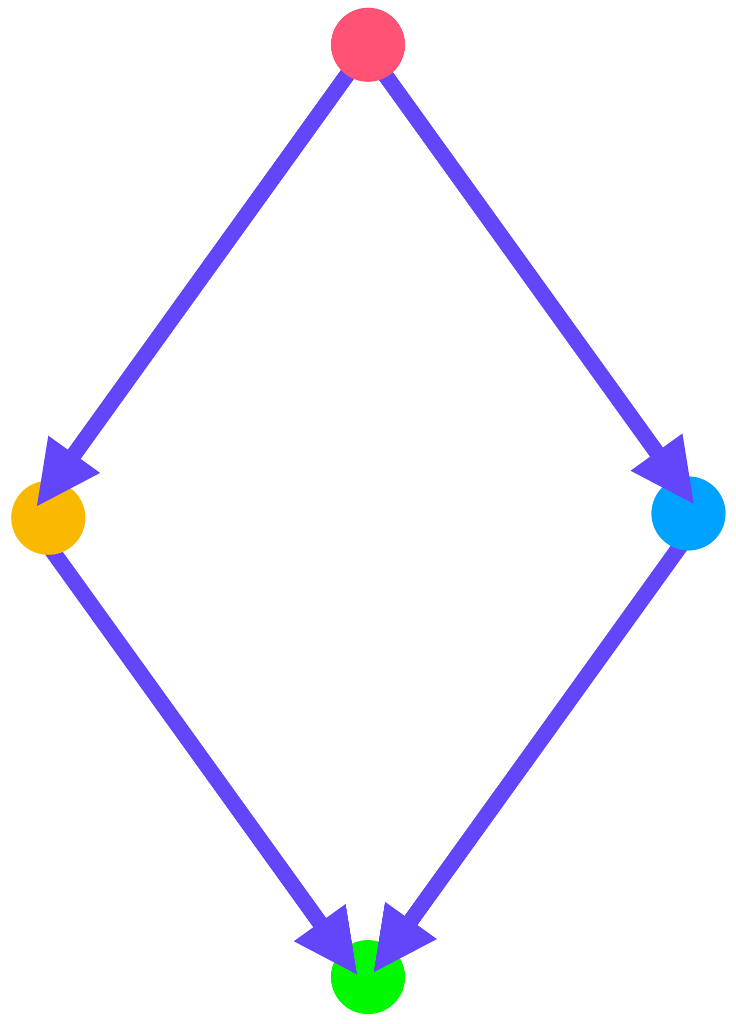

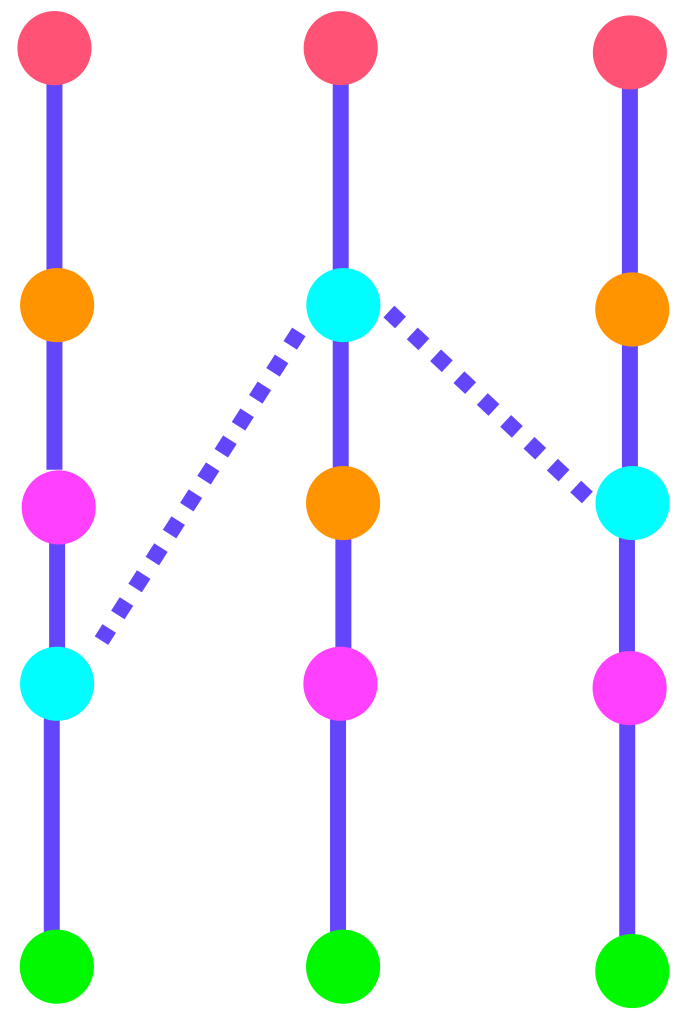

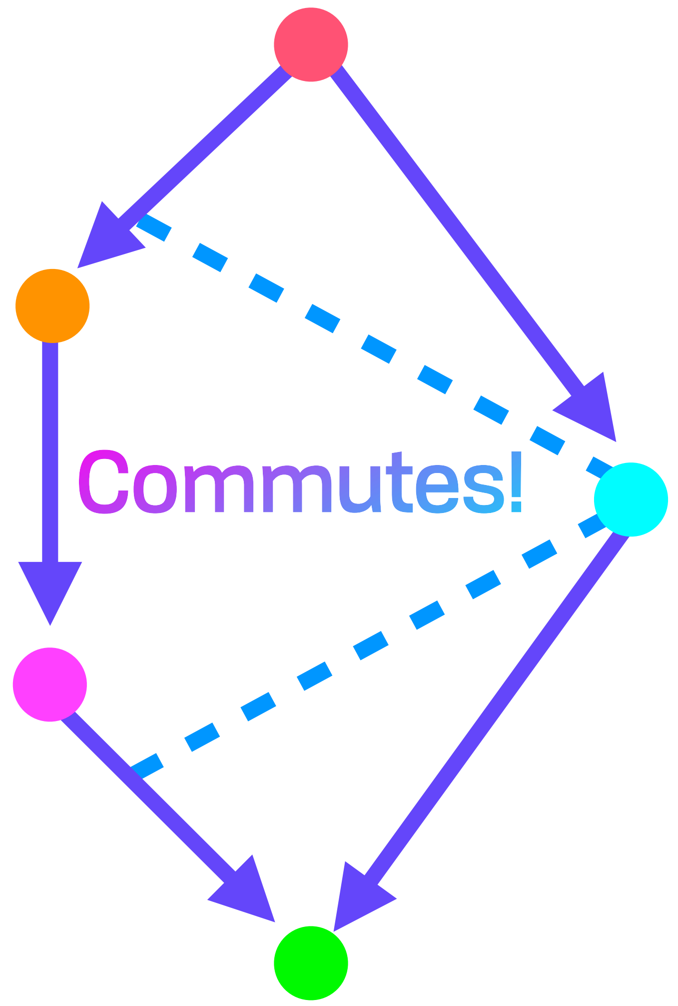

Implicit Parallelism 🥄

Dependency Analysis

Implicit Parallelism 🥄

Dependency Analysis

```
recipient = DB.get(pid, user: 42, field: :email)
msg = IO.gets("What is your message?\n")
msgUpcase = String.uppercase(msg)
receipt = Email.send(msg, to: recipient)
today = Date.utc_today()
DB.insert(pid, "emails", to: recipient, msg: msg, date: today)
```

Implicit Parallelism 🥄

Dependency Analysis

```
recipient = DB.get(pid, user: 42, field: :email)
msg = IO.gets("What is your message?\n")
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Implicit Parallelism 🥄

Dependency Analysis

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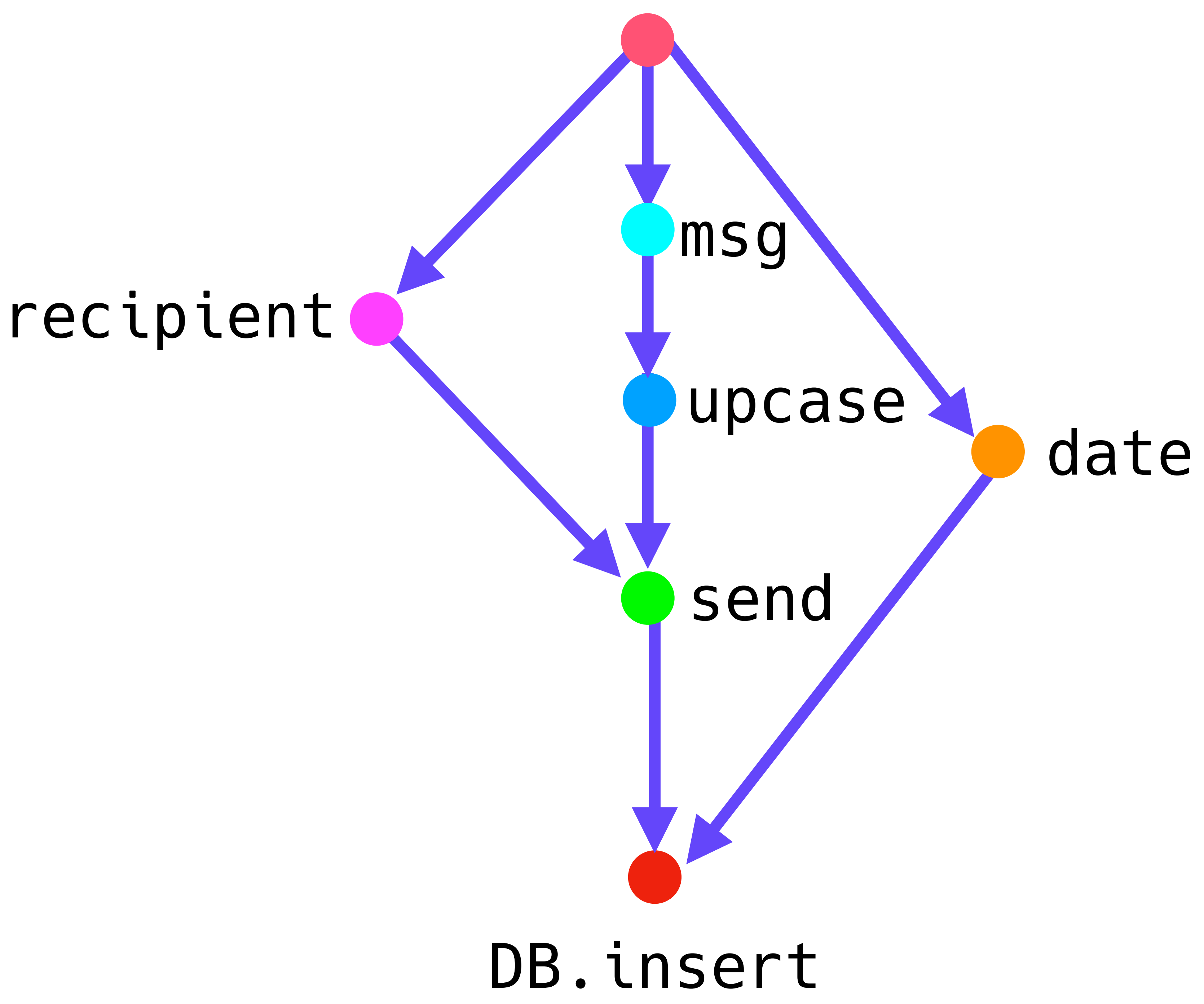

Implicit Parallelism 🥄

Dependency Analysis

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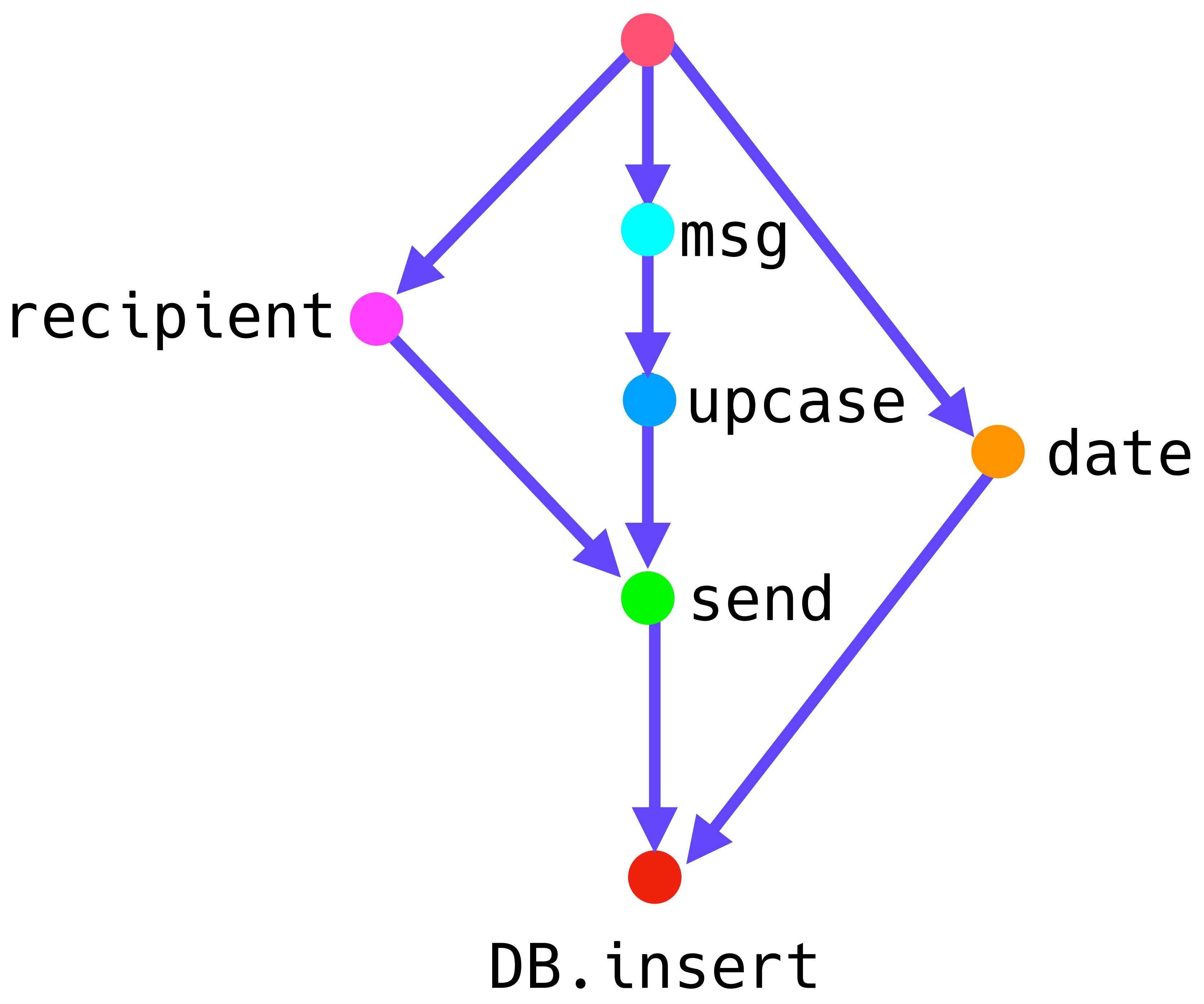


```
Enum.map([1,2,3], fn item ->
  Process.sleep(1000)
  x * 10
end)
```

Implicit Parallelism 🥄

Dependency Analysis

```
recipient = DB.get(pid, user: 42, field: :email)
msg = IO.gets("What is your message?\n")
msgUpcase = String.uppercase(msg)
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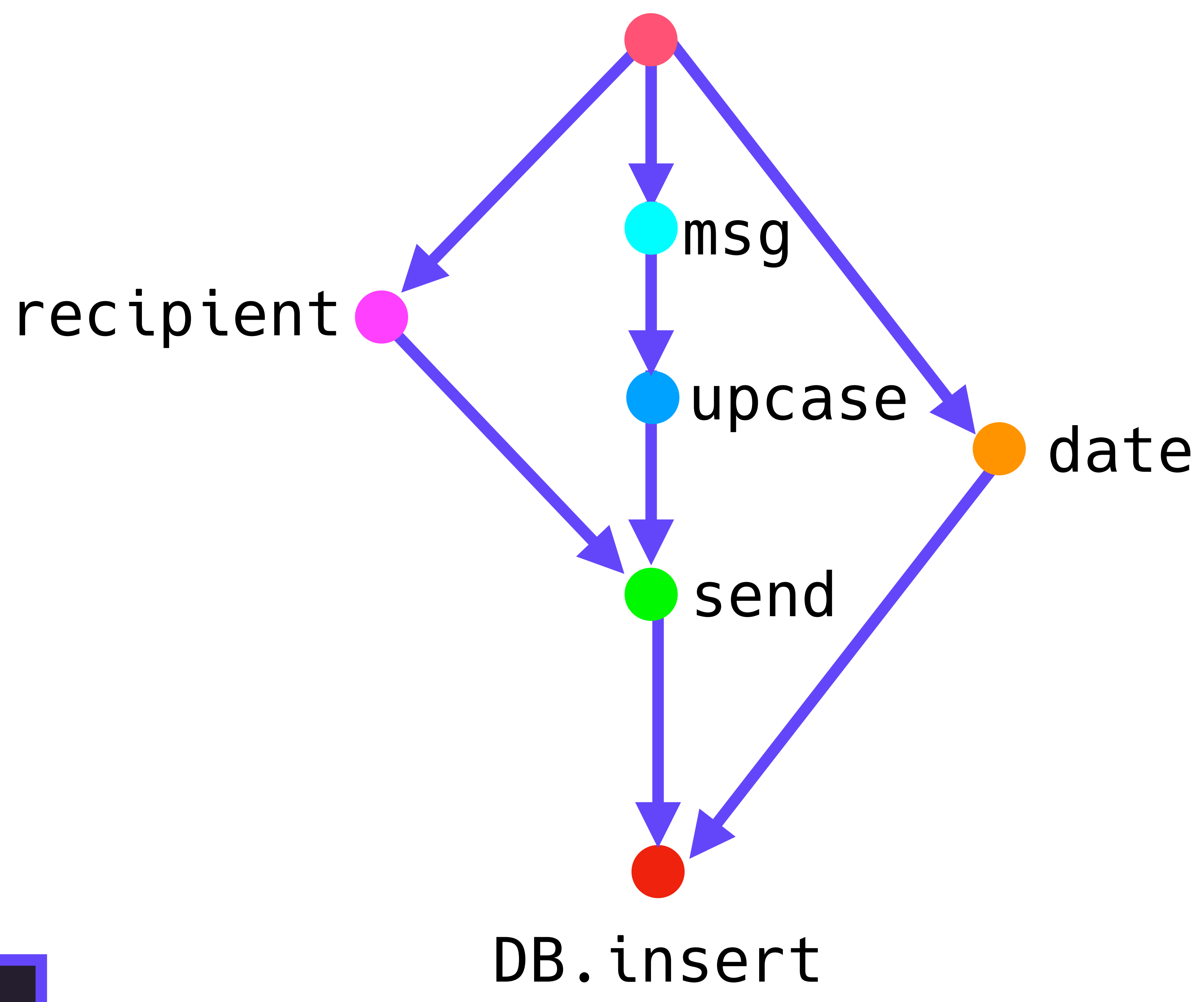


```
Enum.map([1,2,3], fn item ->
  Process.sleep(1000)
  x * 10
end)
```

```
[1,2,3]
|> Enum.map(fn item ->
    Task.async(fn ->
      Process.sleep(1000)
      x * 10
    end)
end)
|> Enum.map(&Task.await/1)
```

Implicit Parallelism 🥄

Dependency Analysis

```elixir
recipient = DB.get(pid, user: 42, field: :email)
msg = IO.gets("What is your message?\n")
msgUpcase = String.uppercase(msg)
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DB.insert(pid, "emails", to: recipient, msg: msg, date: today)
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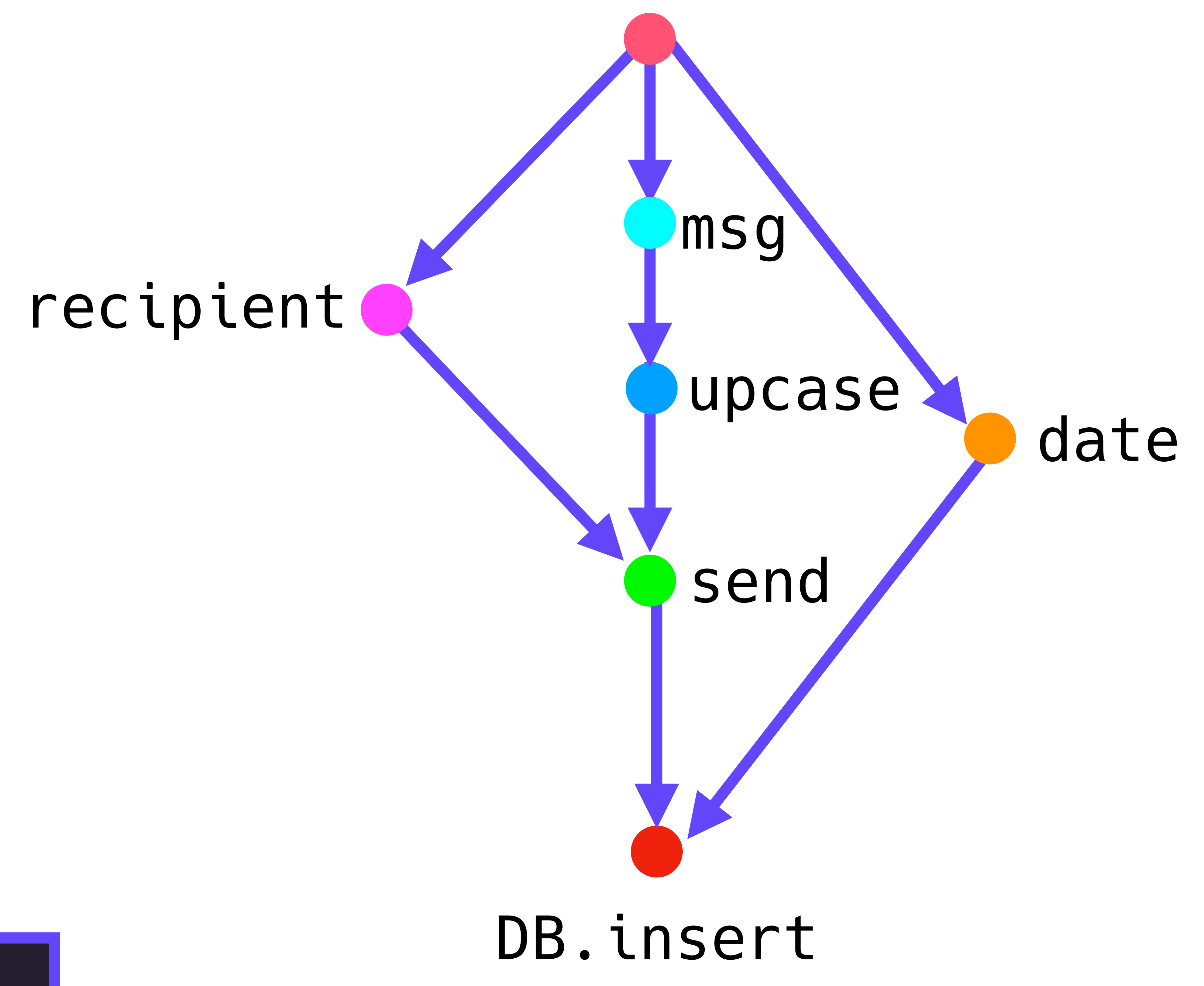


```elixir
Enum.map([1,2,3], fn item ->
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  x * 10
end)
```

```elixir
[1,2,3]
|> Enum.map(fn item ->
    Task.async(fn ->
      Process.sleep(1000)
      x * 10
    end)
end)
|> Enum.map(&Task.await/1)
```

```elixir
[1,2,3]
|> Witchcraft.async_map(fn item ->
  Process.sleep(1000)
  x * 10
end)
```

Implicit Parallelism 🥄

Actor Problem: Data Locality Coordination

Implicit Parallelism 🥄

Actor Problem: Data Locality Coordination

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Implicit Parallelism 🥄

Actor Problem: Data Locality Coordination

Implicit Parallelism 🥄

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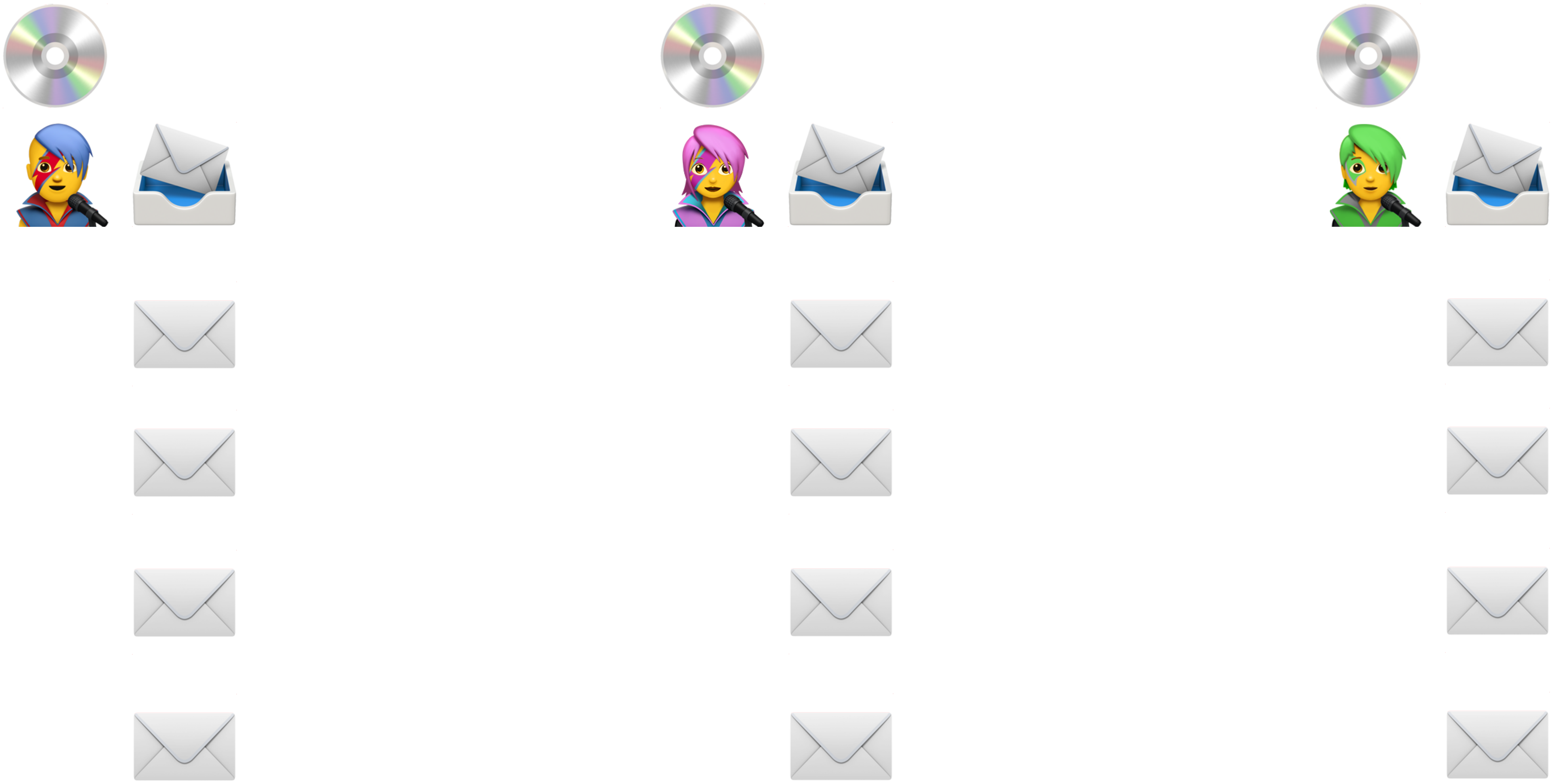
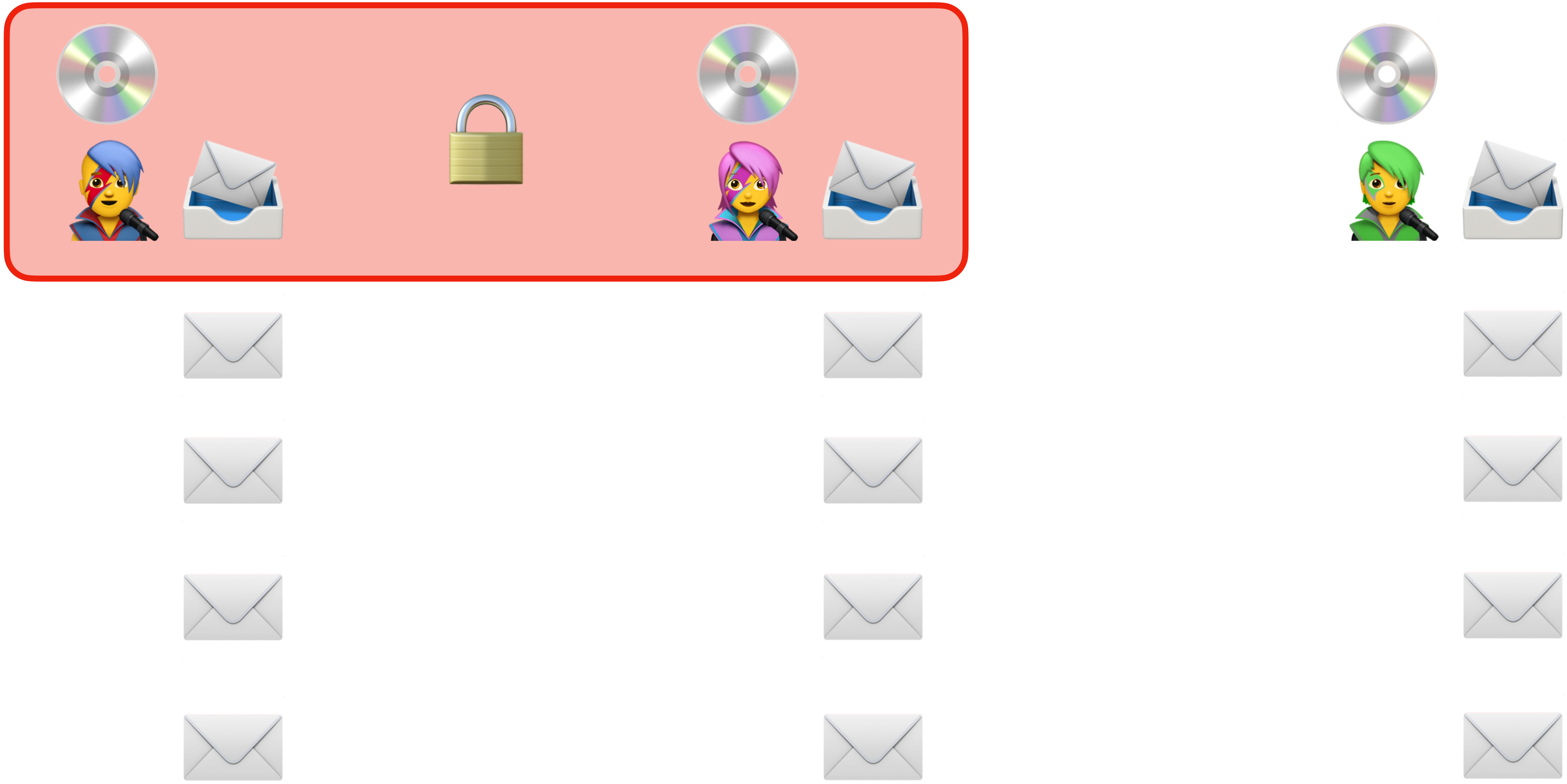
Implicit Parallelism 🥄

Actor Problem: Data Locality Coordination



Implicit Parallelism 🥄

Actor Problem: Data Locality Coordination

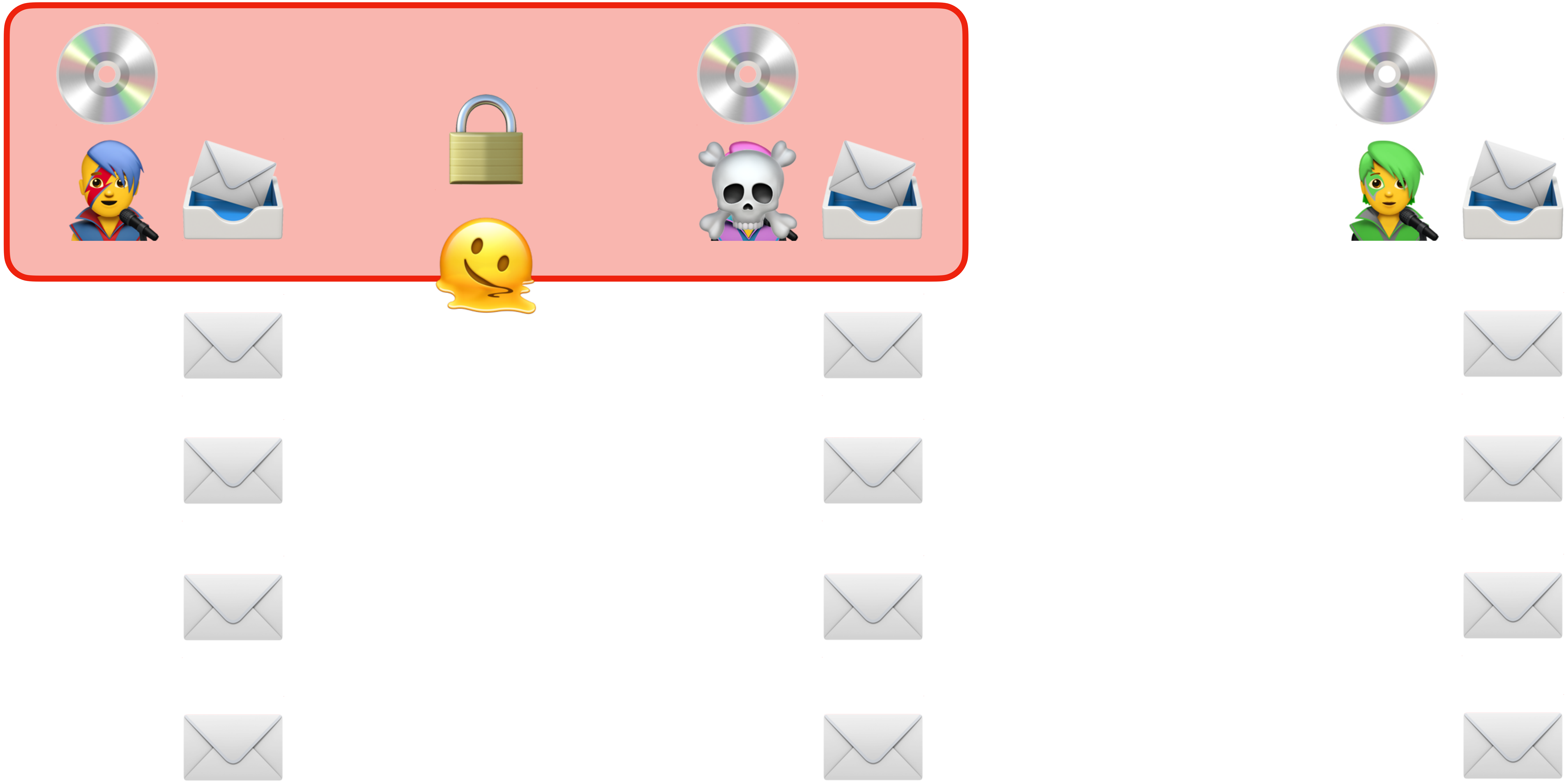


Implicit Parallelism 🥄

Actor Problem: Data Locality Coordination

Implicit Parallelism

Actor Problem: Data Locality Coordination



Purify Your Effects 🦺⛑️🪄

Optimistic Concurrency: STM

https://www.cs.rochester.edu/u/scott/papers/2006_TRANSACT_RSTM.pdf

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Optimistic Concurrency: STM

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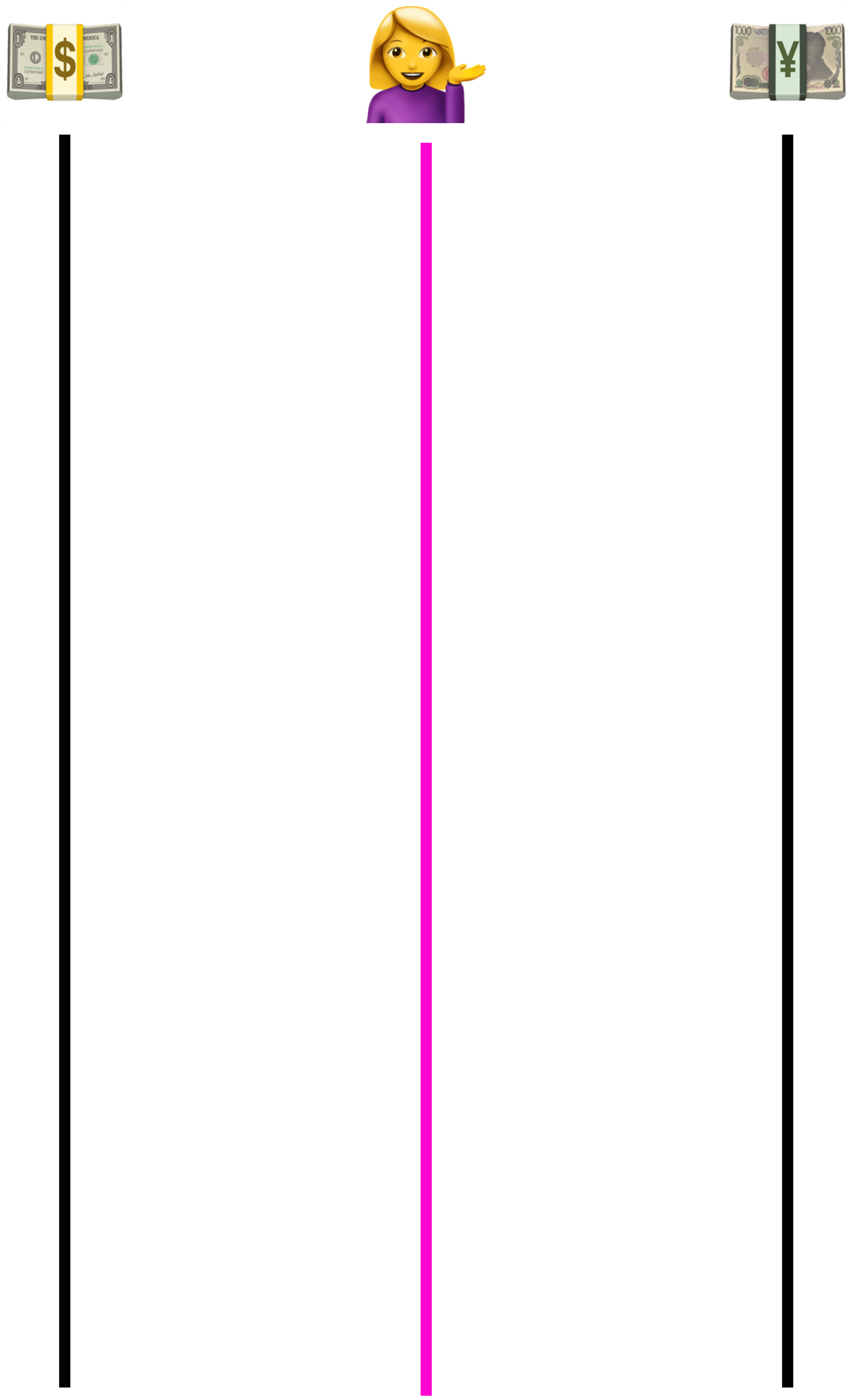
Optimistic Concurrency: STM



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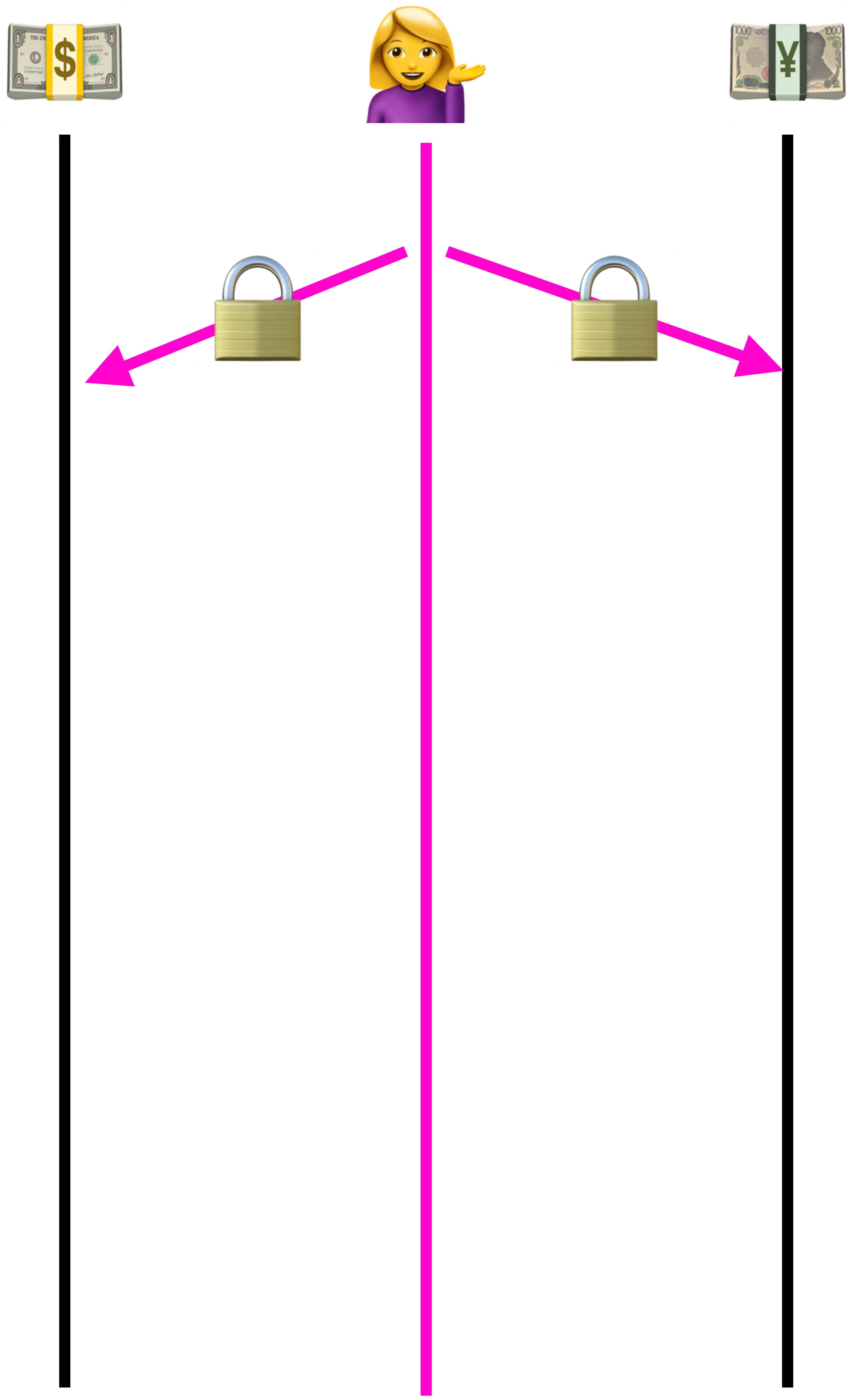

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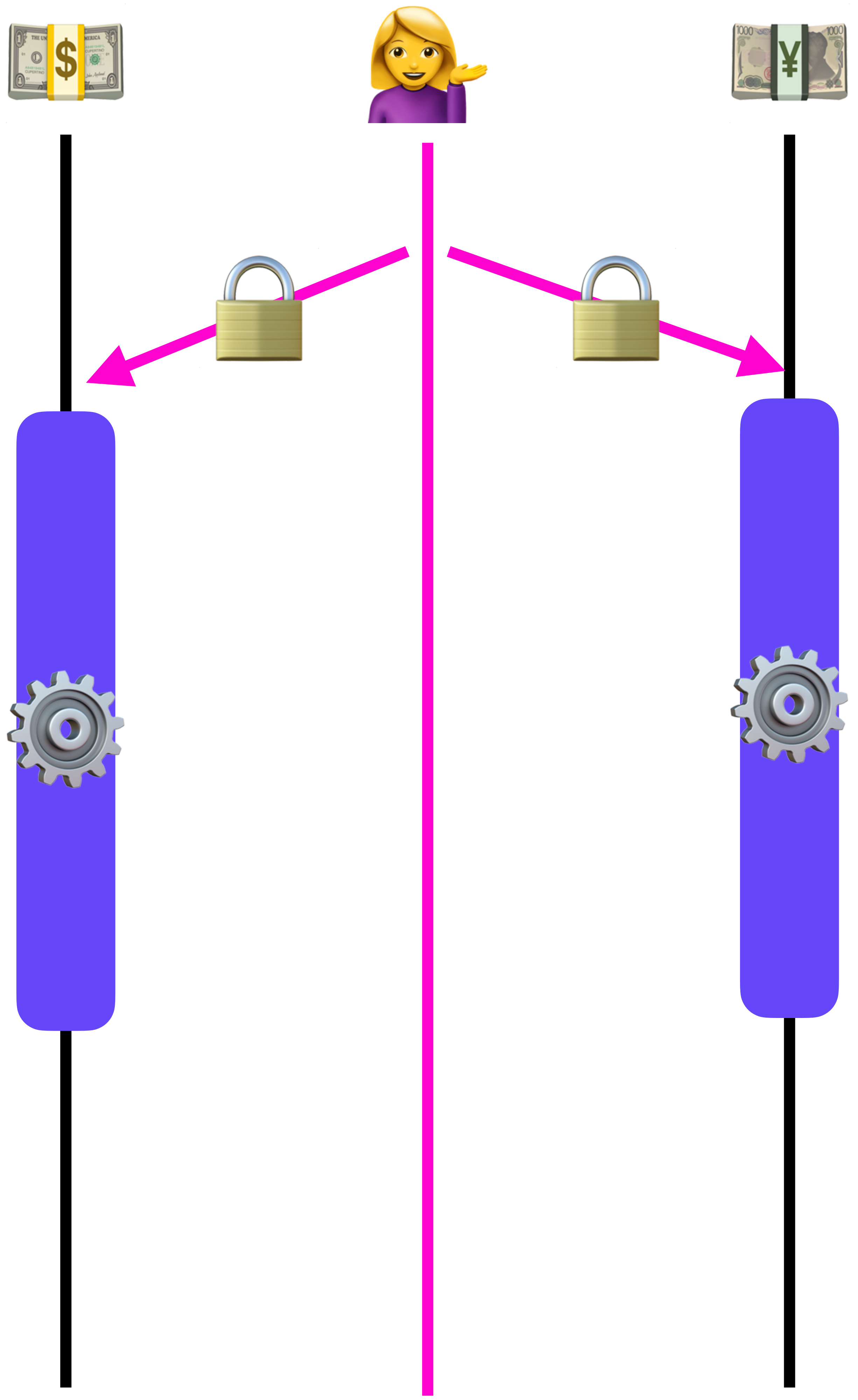

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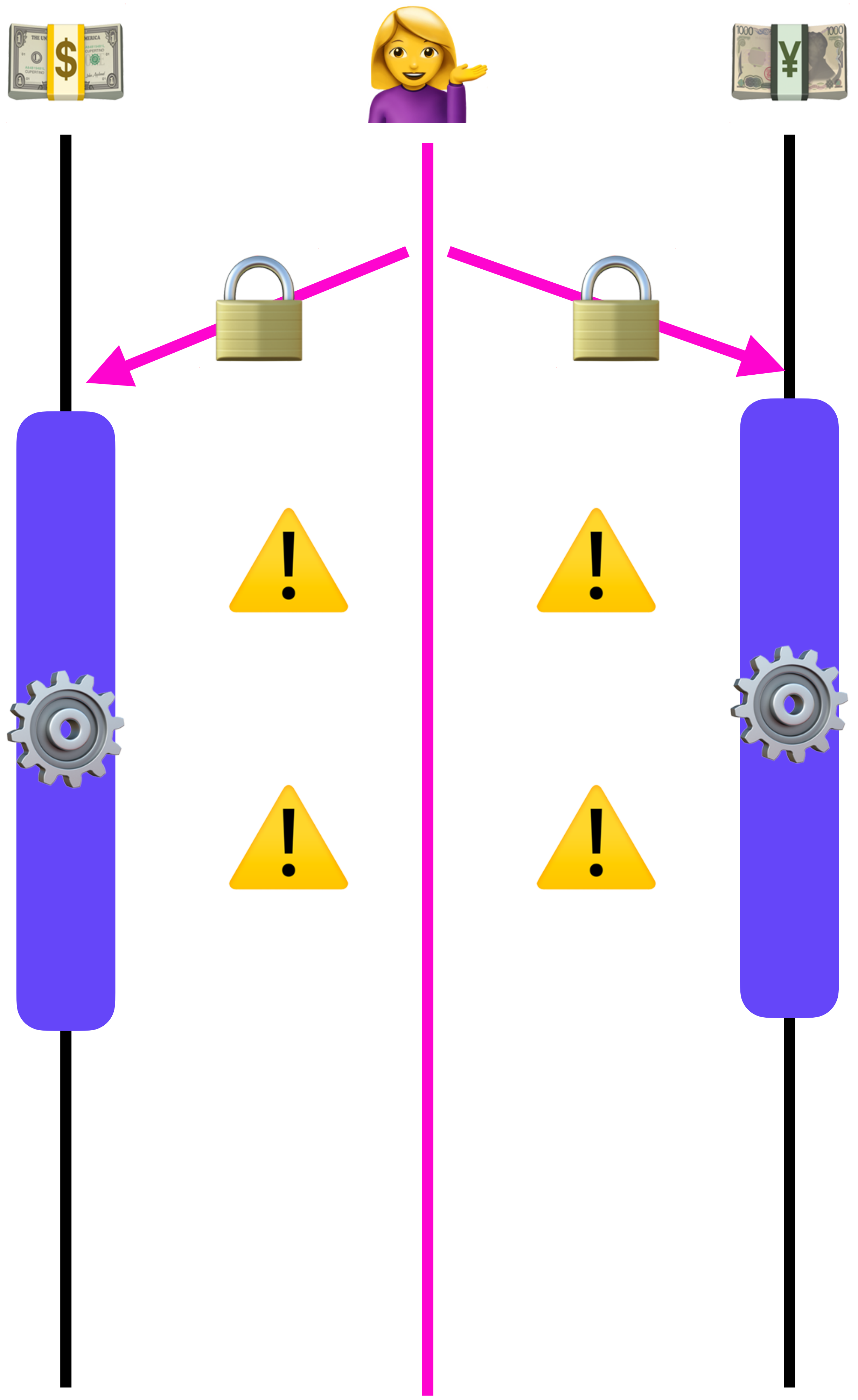

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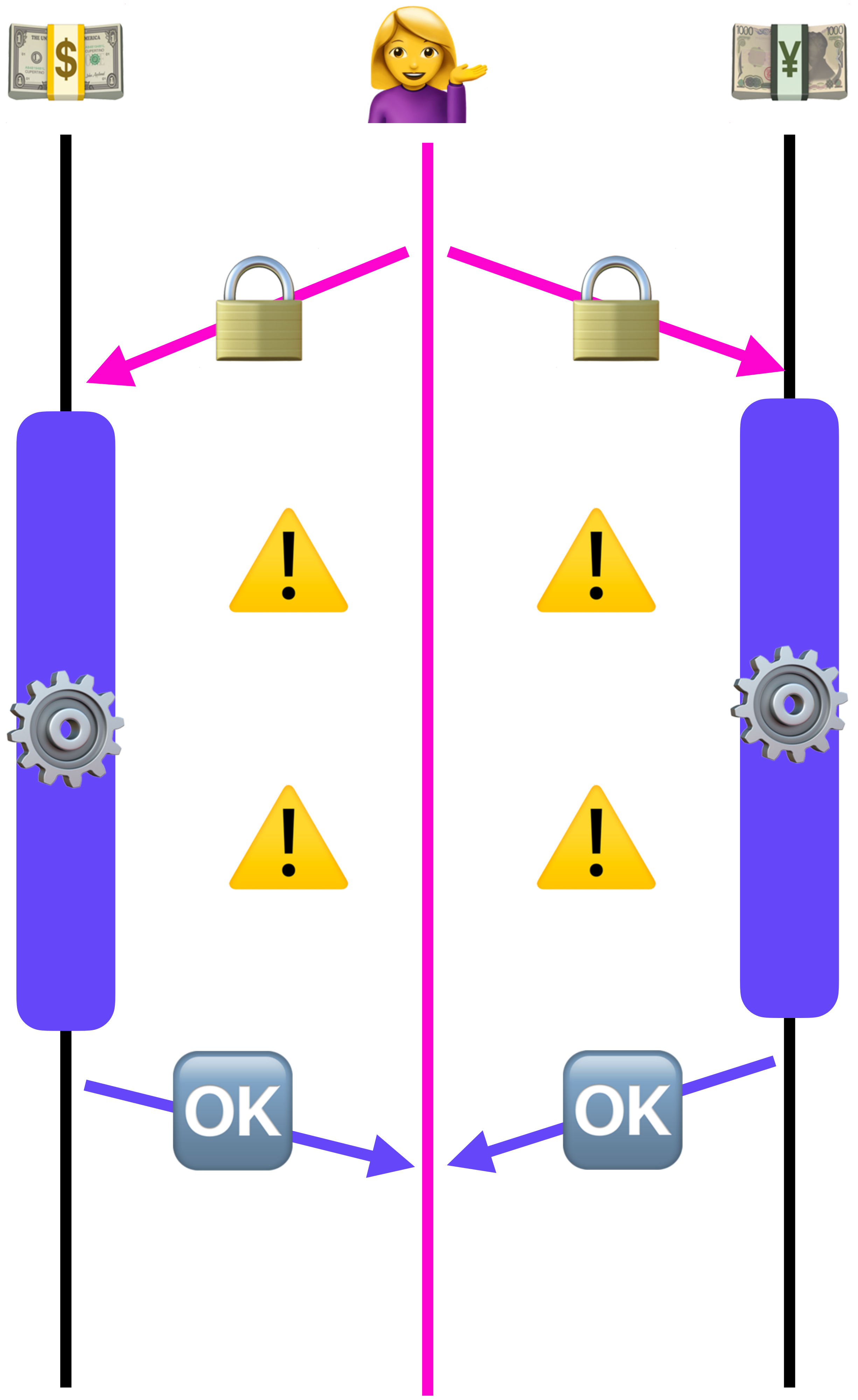

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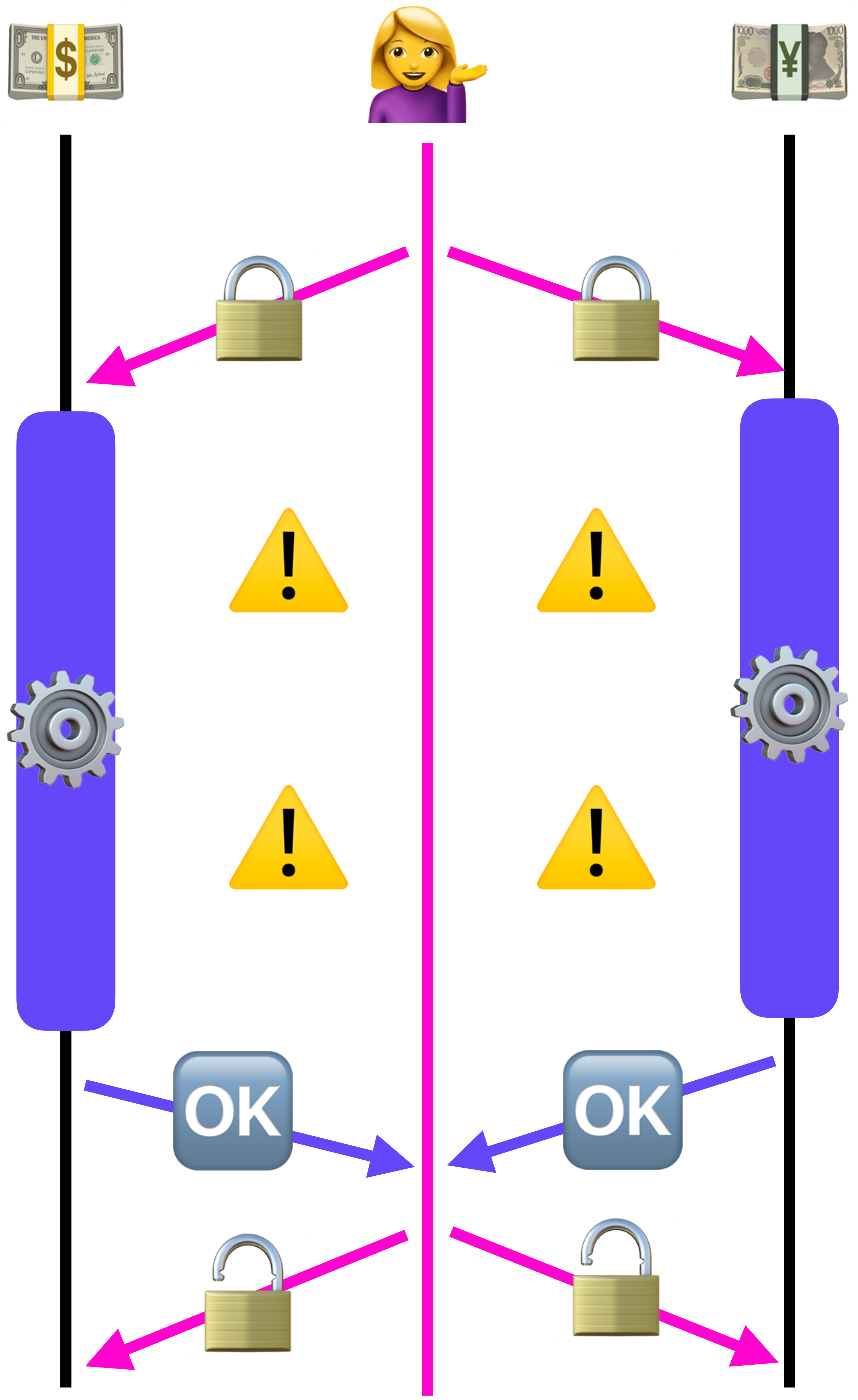

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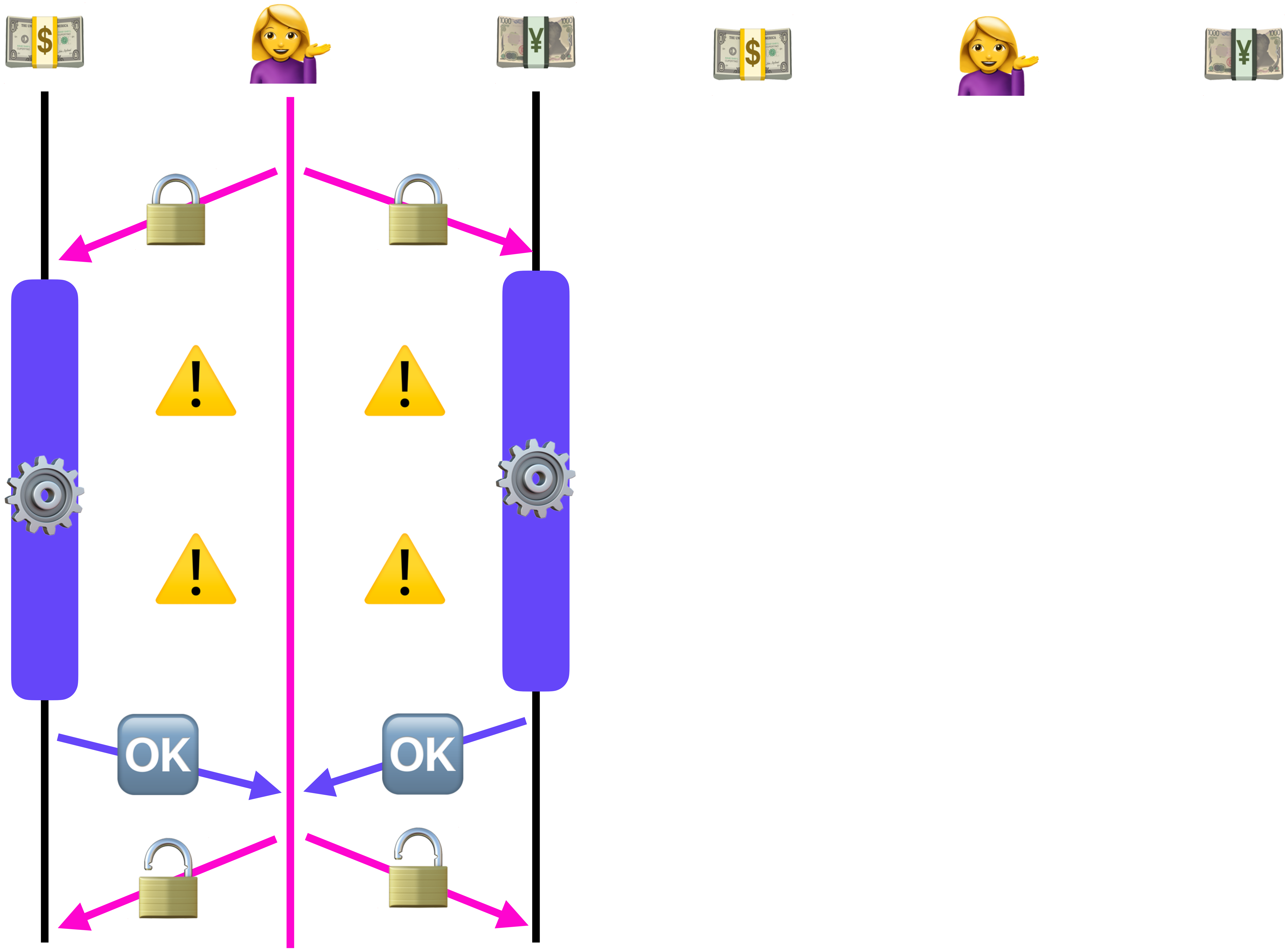

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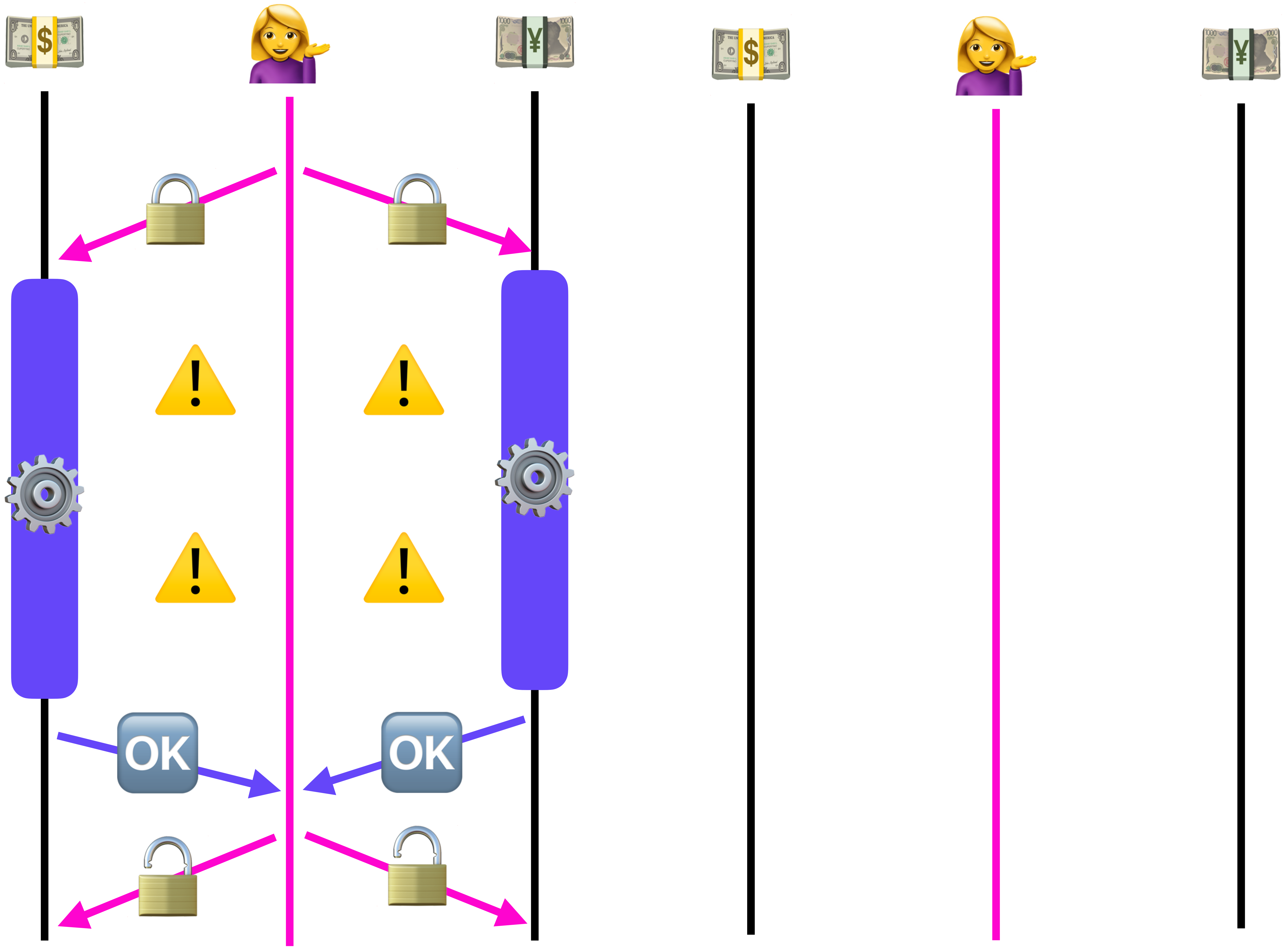

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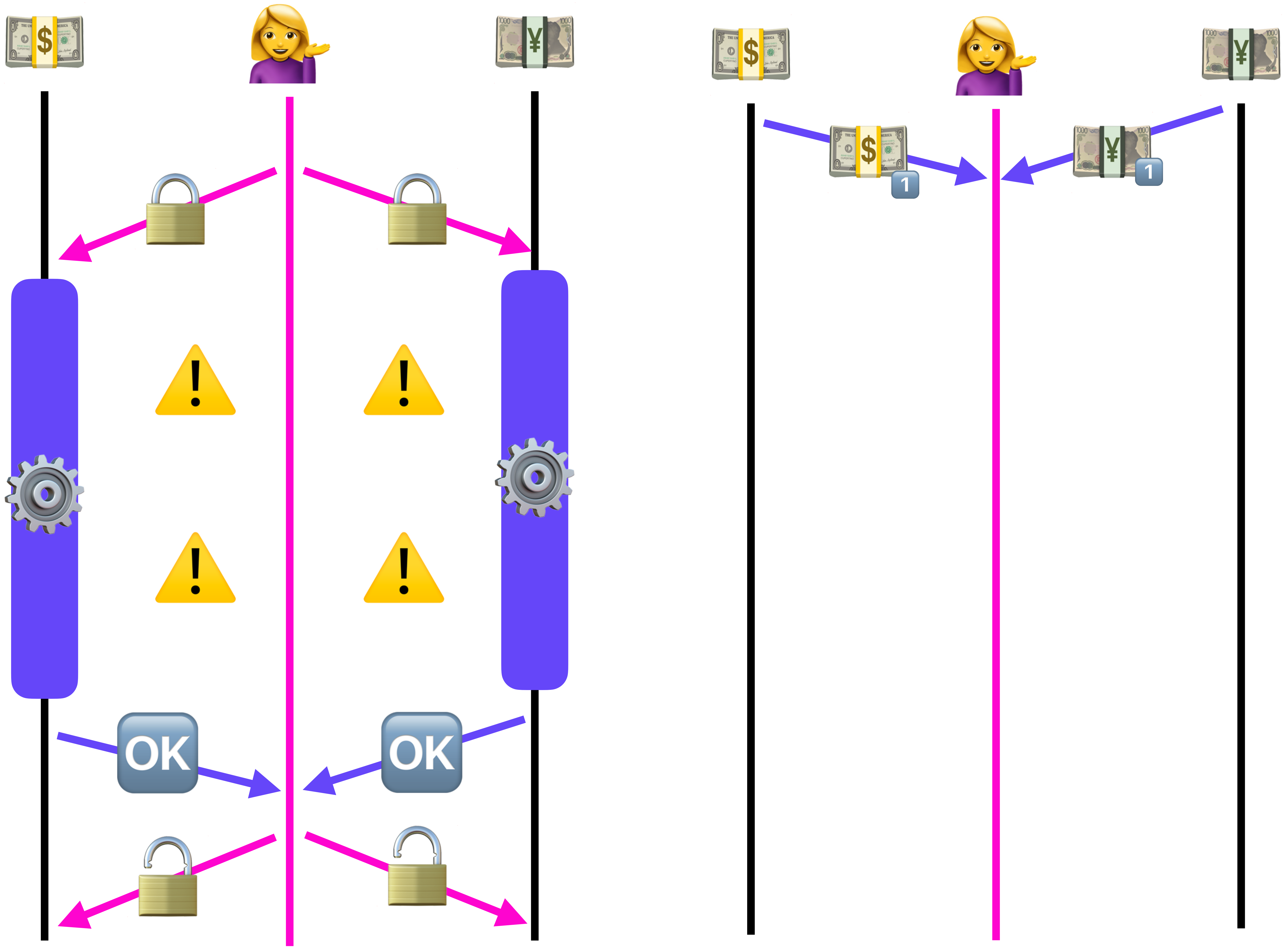

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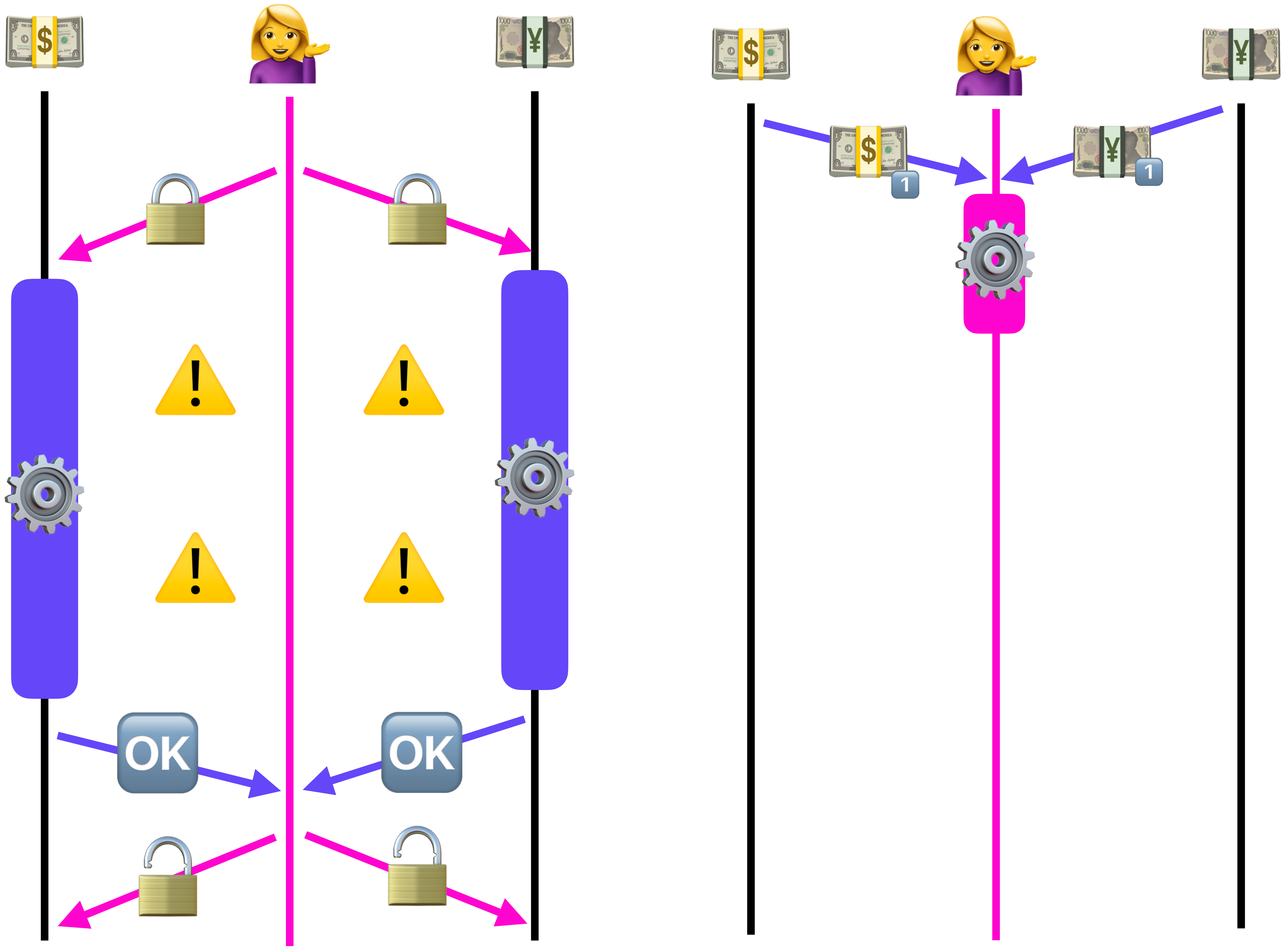

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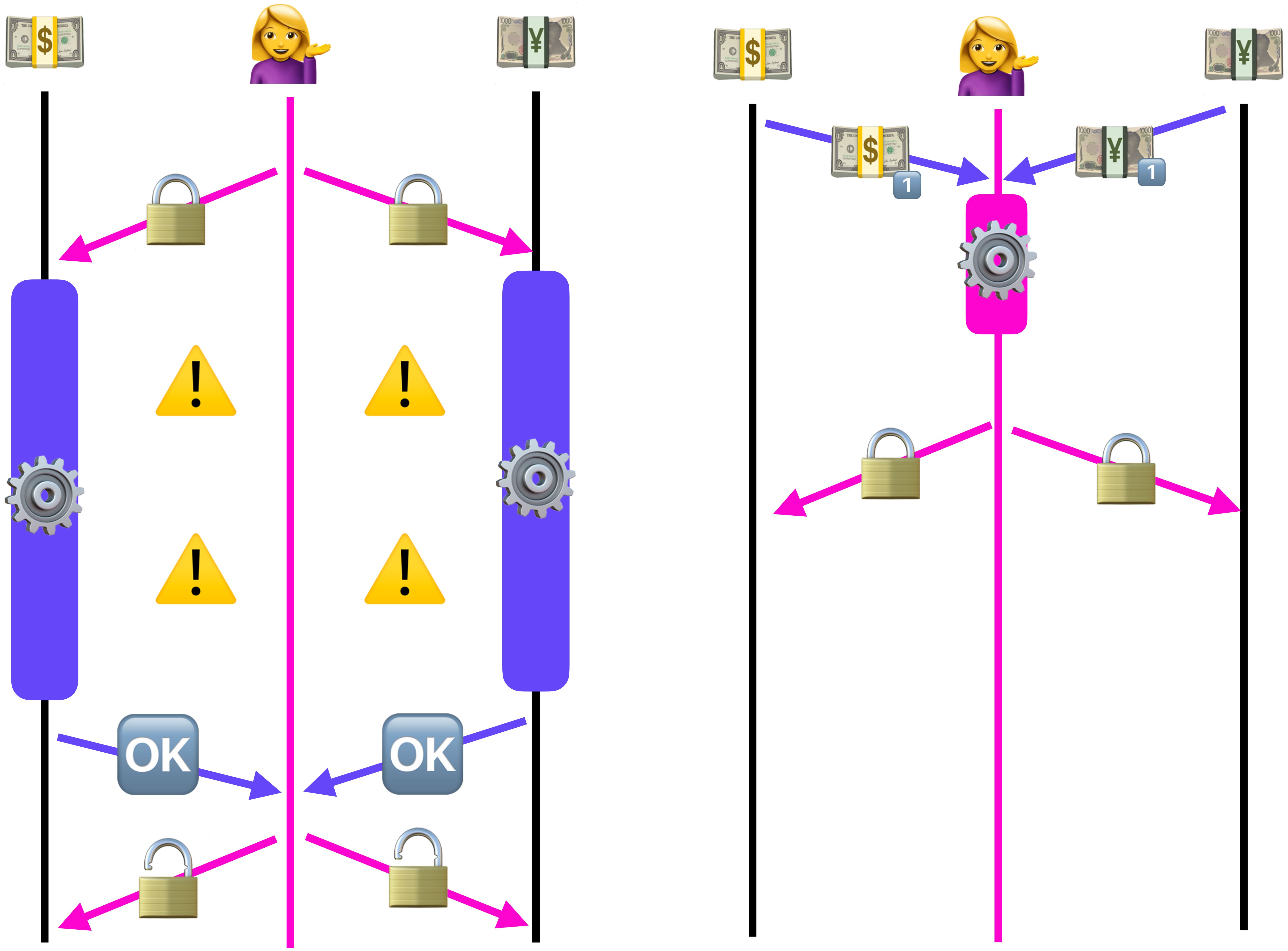

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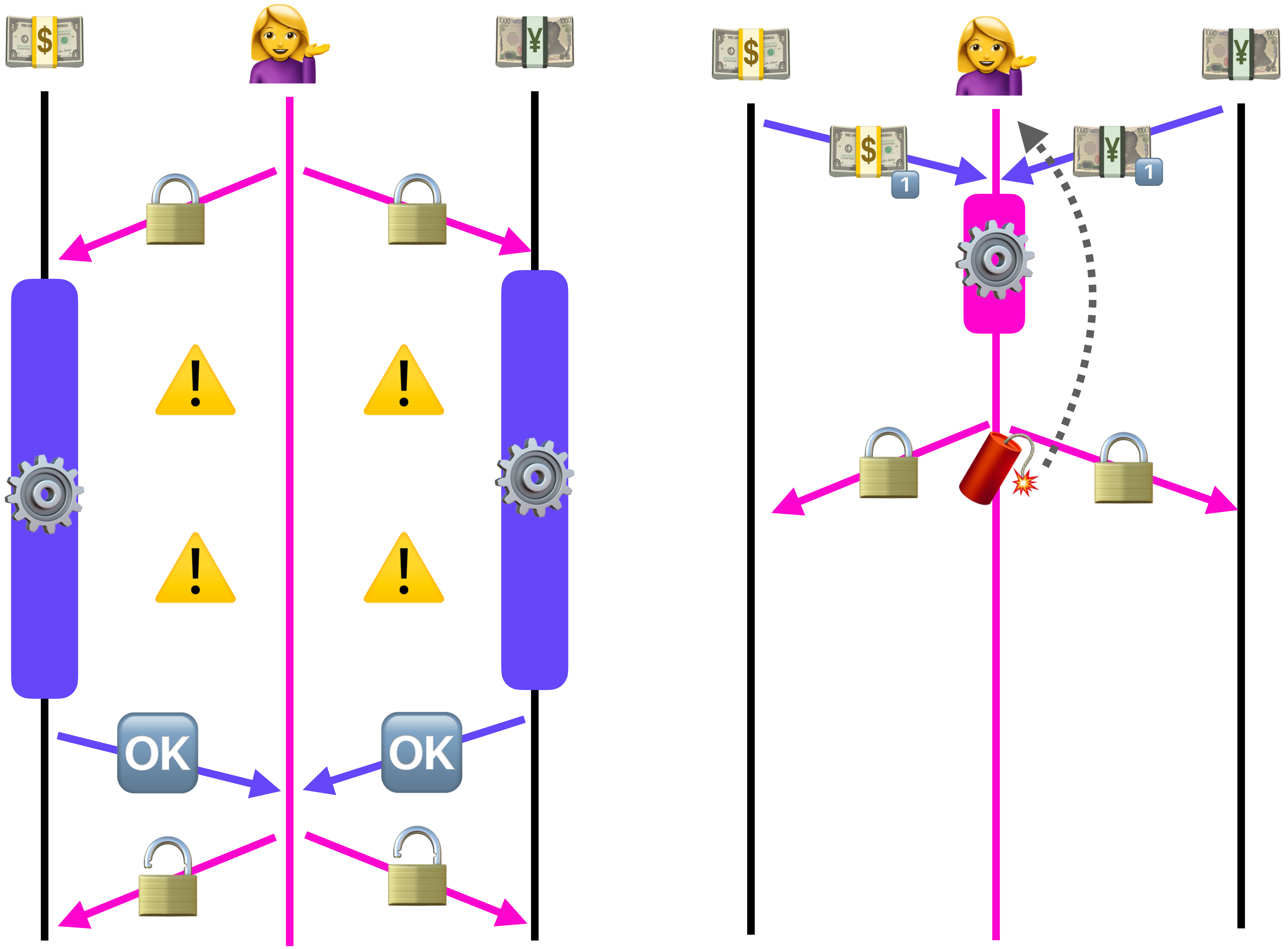

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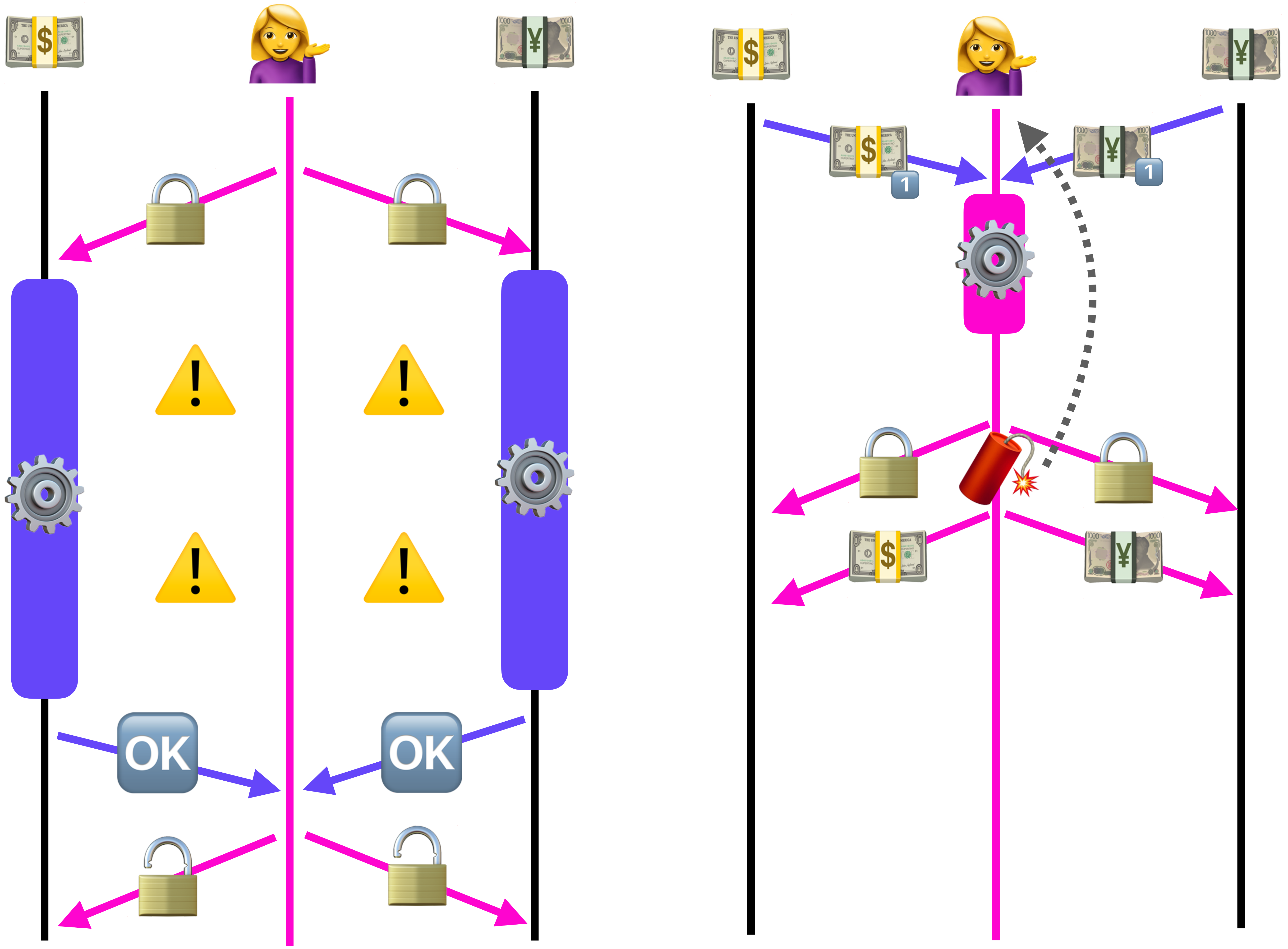

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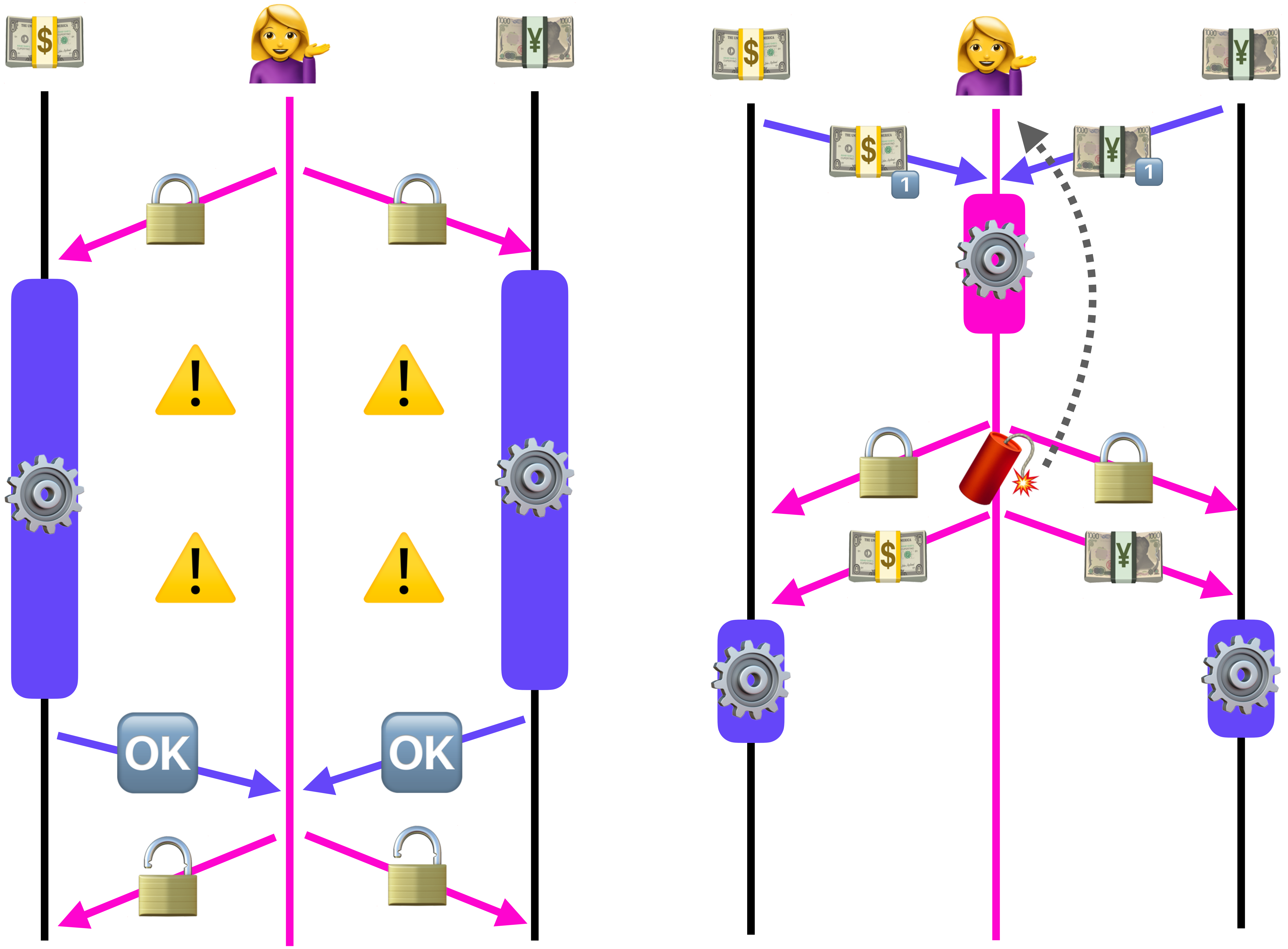

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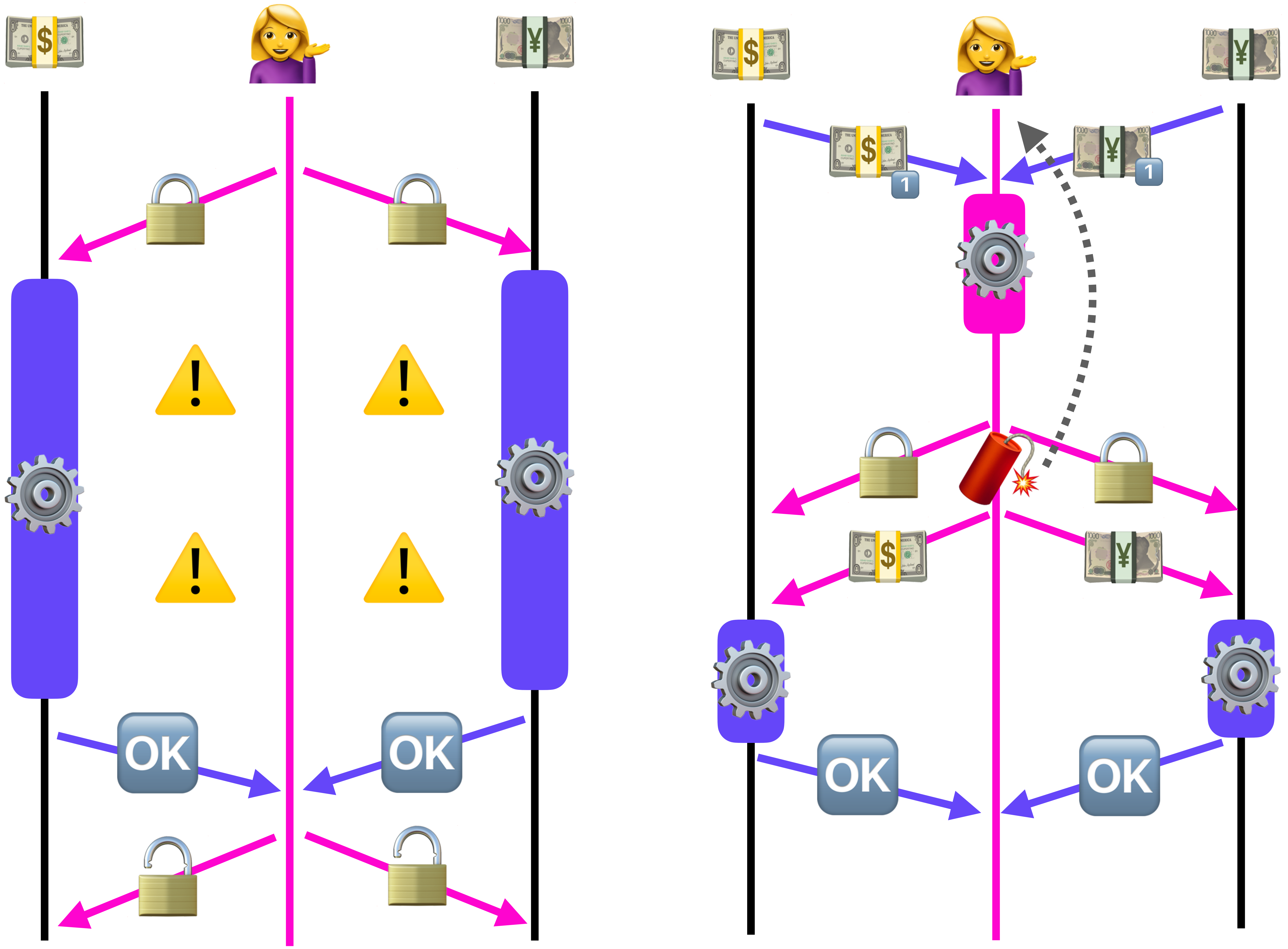

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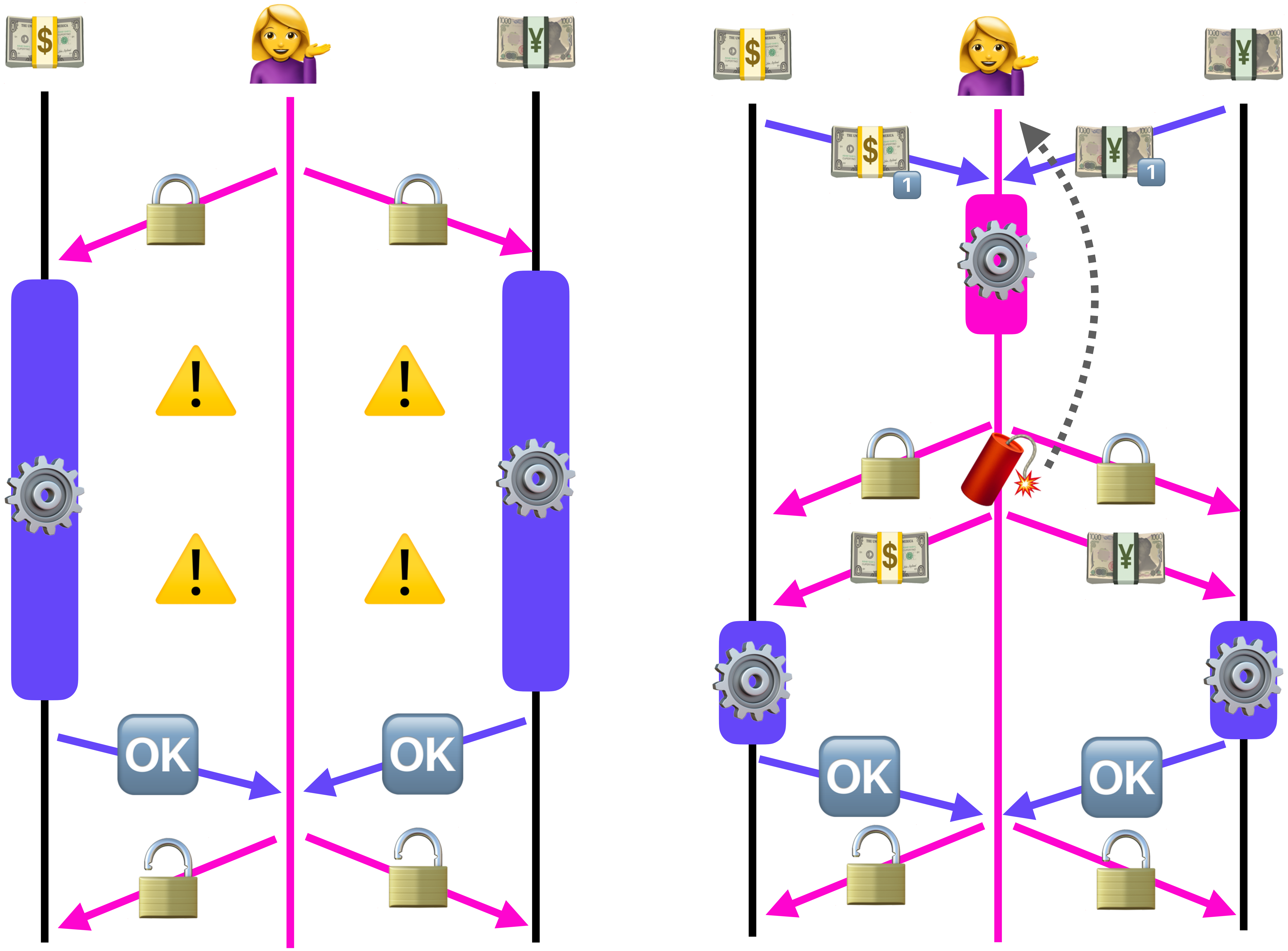

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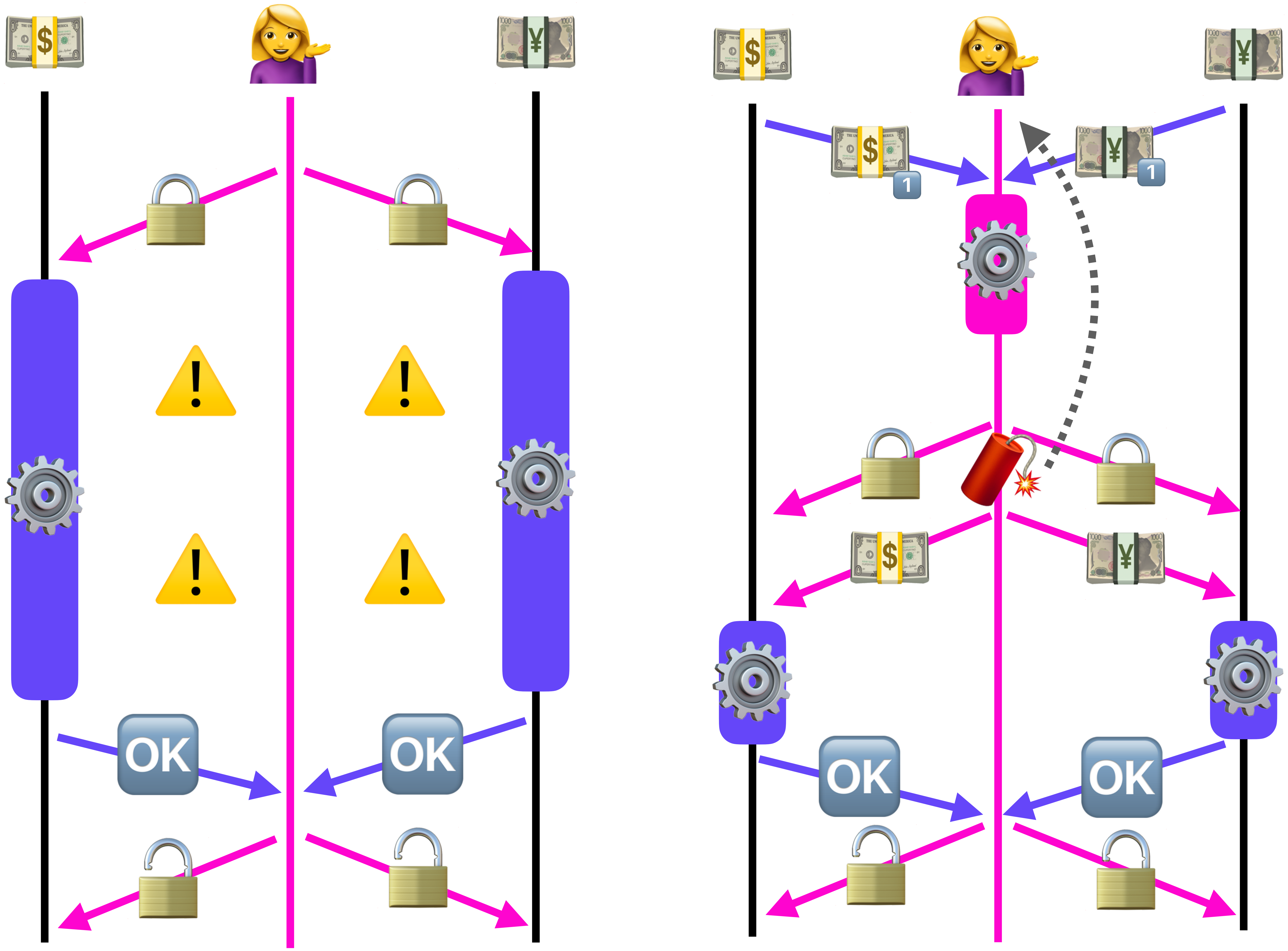
Optimistic Concurrency: STM




```elixir
def transfer(a, b, amount) do
  transact do
    Process.sleep(1000)
    STM.set(a.balance, &(&x + amount))
    STM.set(b.balance, &(&x - amount))
  end

  send_email(to: [a, b], "Transferred $#{amount}")
end
```

https://www.cs.rochester.edu/u/scott/papers/2006_TRANSACT_RSTM.pdf

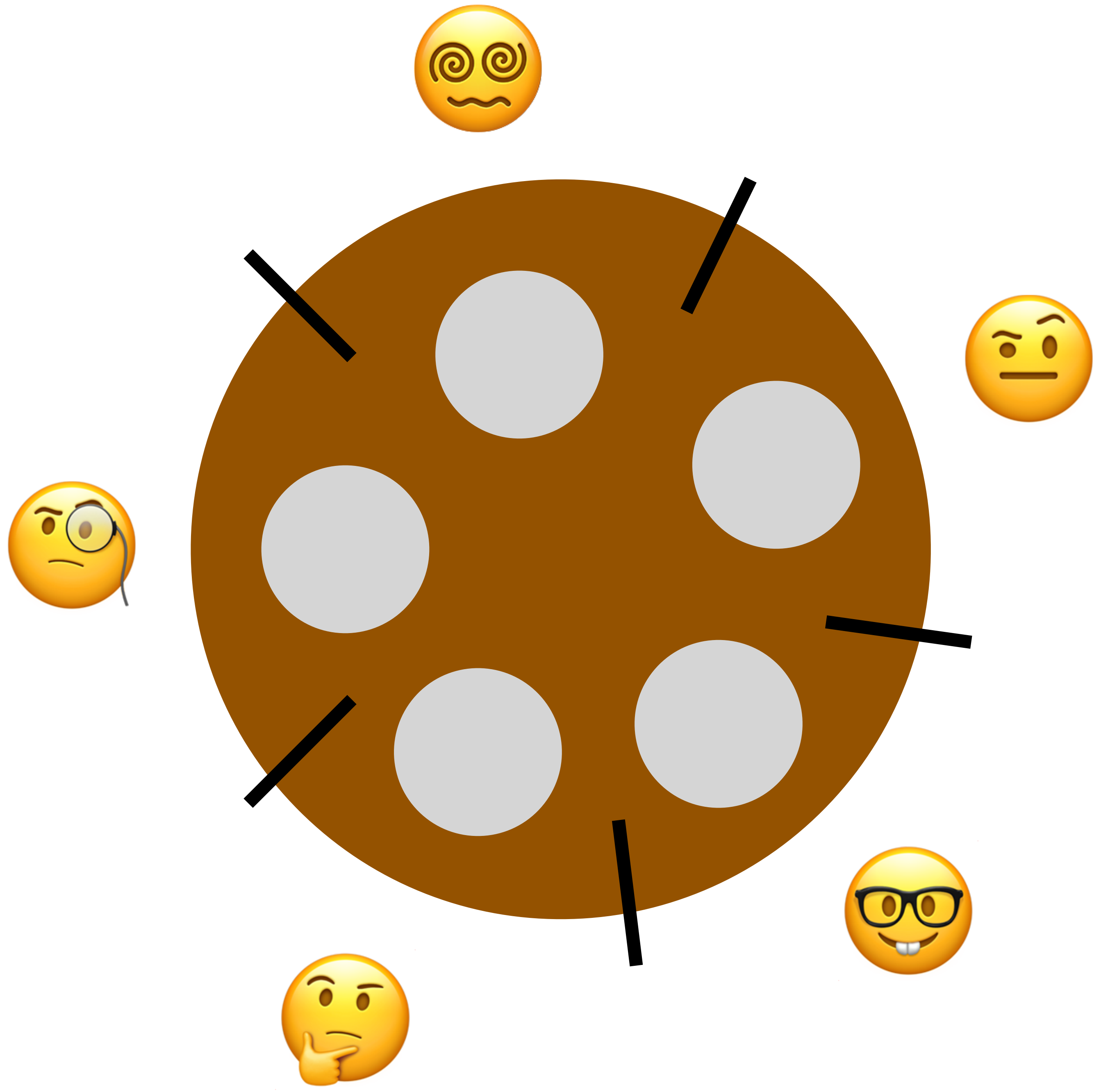
Purify Your Effects 🦺⛑️🪄

Optimistic Concurrency: STM

```
def dine(name, leftStick, rightStick) do
  transact do
    STM.take(leftStick)
    STM.take(rightStick)
  end

  IO.puts("#{name} is eating")
  Process.sleep(Enum.random(0..n))

  transact do
    STM.put(leftStick, :chopstick)
    STM.put(rightStick, :chopstick)
  end
end
```



Optimistic Concurrency: STM

Effectful Proof, Provenance, & Power

Metadata in Motion

Effectful Proof, Provenance, & Power

Metadata in Motion

Metadata in Motion 📦💨

It's only ***data provenance*** if it's derived from the ***Provence region of France.*** Otherwise it's just ***sparkling metadata.***

– Adapted from @onfiv

Metadata in Motion 📦💨

Proof Carrying Code

Metadata in Motion 📦💨

Proof Carrying Code

```
defmodule NonEmptyList do
  defstruct [:head, :tail]

  def singleton(x) do
    %NonEmptyList{head: x, tail: []}
  end

  def to_list(%NonEmptyList{head: head, tail: tail}) do
    [head | tail]
  end

  def from_list([]), do: :empty
  def from_list([x | xs]), do: %NonEmptyList{head: x, tail: xs}
end

defimpl Enumerable, for: NonEmptyList do
  def count(%NonEmptyList{tail: tail}) do
    count(rest) + 1
  end
end
```

Metadata in Motion 📦💨

Proof Carrying Code

```elixir
defmodule NonEmptyList do
  defstruct [:head, :tail]

  def singleton(x) do
    %NonEmptyList{head: x, tail: []}
  end

  def to_list(%NonEmptyList{head: head, tail: tail}) do
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  end

  def from_list([]), do: :empty
  def from_list([x | xs]), do: %NonEmptyList{head: x, tail: xs}
end

defimpl Enumerable, for: NonEmptyList do
  def count(%NonEmptyList{tail: tail}) do
    count(rest) + 1
  end
end
```

```elixir
%NonEmptyList{
  head: 0,
  tail: [1,2,3]
}
```

Metadata in Motion 📦💨

Proof Carrying Code

```elixir
defmodule NonEmptyList do
  defstruct [:head, :tail]

  def singleton(x) do
    %NonEmptyList{head: x, tail: []}
  end

  def to_list(%NonEmptyList{head: head, tail: tail}) do
    [head | tail]
  end

  def from_list([]), do: :empty
  def from_list([x | xs]), do: %NonEmptyList{head: x, tail: xs}
end

defimpl Enumerable, for: NonEmptyList do
  def count(%NonEmptyList{tail: tail}) do
    count(rest) + 1
  end
end
```

```elixir
%NonEmptyList{
  head: 0,
  tail: [1,2,3]
}
```

```elixir
%Sorted{
  by: :lex,
  enum: ["a", "b", "cdef"]
}

%Sorted{
  by: :lex,
  enum: ["b", "z"]
}
```

Metadata in Motion 📦💨

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mergesort is way easier now

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Carrying Capabilities

https://kataskeue.com/gdp.pdf
https://arxiv.org/pdf/1907.07154.pdf

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Carrying Capabilities

```
%CanDo {
  caps: [
    %{can: :overwrite, directory: "/tmp/files/"},
    %{can: :send_email, as: "boris@fission.codes"}
  ],
  for: %User{id: 42},
  session: 123
}
```

https://kataskeue.com/gdp.pdf
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Carrying Capabilities

```
%CanDo {
  caps: [
    %{can: :overwrite, directory: "/tmp/files/"},
    %{can: :send_email, as: "boris@fission.codes"}
  ],
  for: %User{id: 42},
  session: 123
}
```

```
def send_email(%CanDo{caps: caps, for: user}, msg, to) do
  case find_send(caps) do
    %{to: address} -> Email.send(from: user, to: address)
    nil -> :unauthorized
  end
end
```

https://kataskeue.com/gdp.pdf
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Metadata in Motion 📦💨

Provenance

Metadata in Motion 📦💨

Provenance

```
%Rememeber{
  value: 42,
  history: [
    %{value: 37},
    %{value: 109}
  ]
}
```

Metadata in Motion 📦💨

Provenance

```
%Rememeber{
  value: 42,
  history: [
    %{value: 37},
    %{value: 109}
  ]
}
```

```
%BranchableHistory{
  value: 42,
  histories: [
    %Branch{
      histories: [
        %{value: 12},
        %{value: 0},
      ]
    },
    %Branch{
      histories:[
        %{value: 37},
        %{value: 109},
      ]
    },
    %{value: 0}
  ]
}
```

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Provenance

```
%Rememeber{
  value: 42,
  history: [
    %{value: 37},
    %{value: 109}
  ]
}
```

```
%BranchableHistory{
  value: 42,
  histories: [
    %Branch{
      histories: [
        %{value: 12},
        %{value: 0},
      ]
    },
    %Branch{
      histories:[
        %{value: 37},
        %{value: 109},
      ]
    },
    %{value: 0}
  ]
}
```

```
Logger.debug("#{__ENV__.file}:#{__ENV__.line}: #{inspect some_value}")
```

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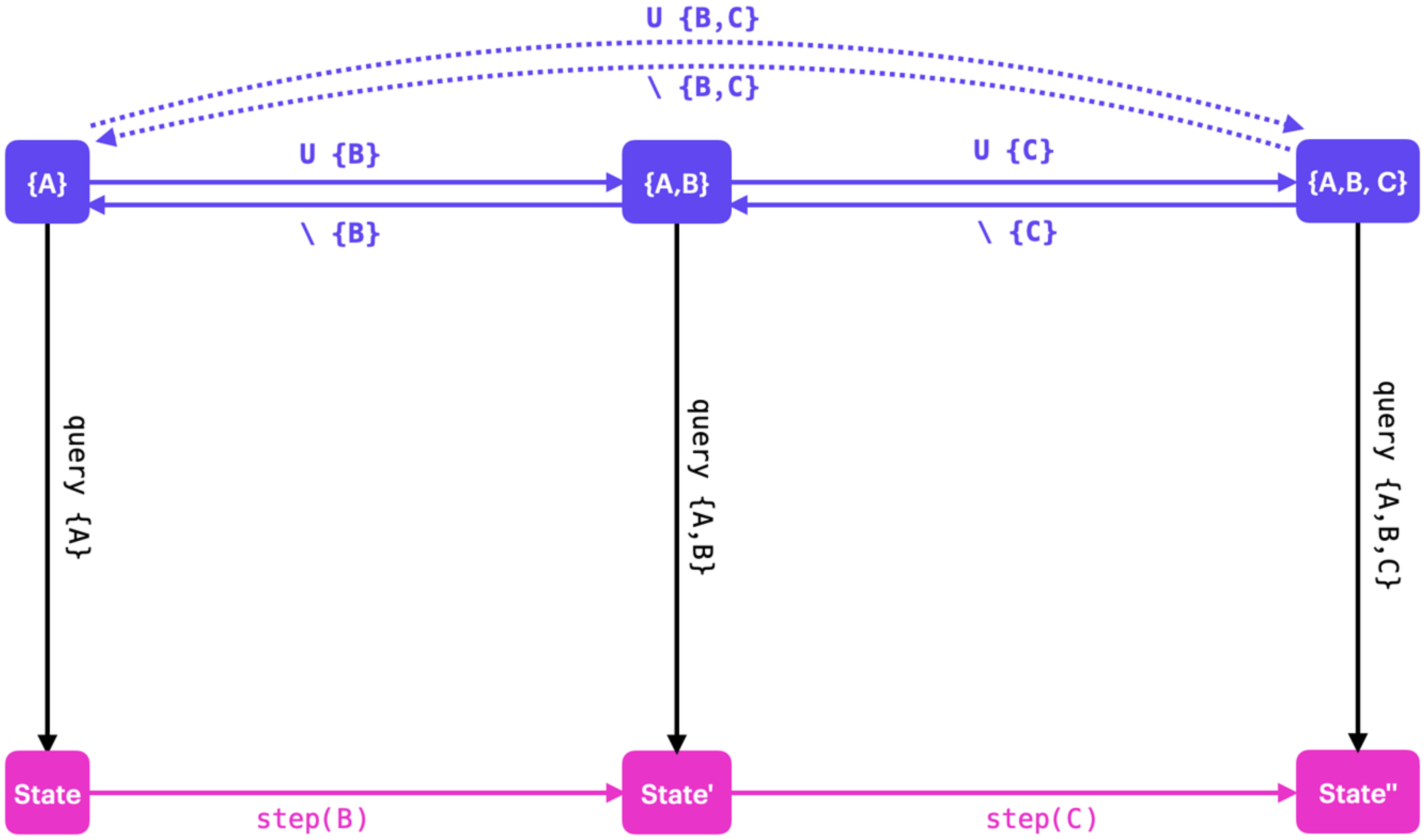
Provenance++



Tools for The Intrepid

⚒️

Wrapping Up

Tools for The Intrepid

Tools for The Intrepid ⚒️

A programming language ***influences the way that its users think*** about programming; matching a language to a methodology ***increases the likelihood that the methodology will be used***

– Barbara Liskov et al, Abstraction Mechanisms in CLU

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What Just Happened?

Tools for The Intrepid ⚒️

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1. Add structure & dimension

Tools for The Intrepid ⚒️

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1. Add structure & dimension

2. Make reusable DSLs

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3. Manage your effects

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4. Mechanize the hard stuff (e.g. concurrency)

Tools for The Intrepid ⚒️

What Just Happened?

1. Add structure & dimension
2. Make reusable DSLs
3. Manage your effects
4. Mechanize the hard stuff (e.g. concurrency)
5. Pass around context

Tools for The Intrepid ⚒️

Is this the future?

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I don't know! 🤷‍♀️

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We need to ***experiment*** with more directions

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I don't know! 🤷‍♀️

We need to ***experiment*** with more directions

These are but a few options

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I don't know! 🤷‍♀️

We need to ***experiment*** with more directions

These are but a few options

Go explore! 🧭

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I don't know! 🤷‍♀️

We need to ***experiment*** with more directions

These are but a few options

Go explore! 🧭

(And share what you find)

🎉 Thank You, Salt Lake City! 🇺🇸

✦ https://lu.ma/distributed-systems

https://fission.codes/discord

github.com/expede

@expede