Reasoning about Deltas —
Even Doing Nothing is Difficult

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Amazon Web Services

Takeaway

- Problem: reasoning about specifications deltas is difficult
- Need: automated proof engineering
- Solution: typeCart, an analysis tool

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- Application: relating two specification versions of AWS authorization engine

Evolving Specifications for Evolving Implementations

specifications
code

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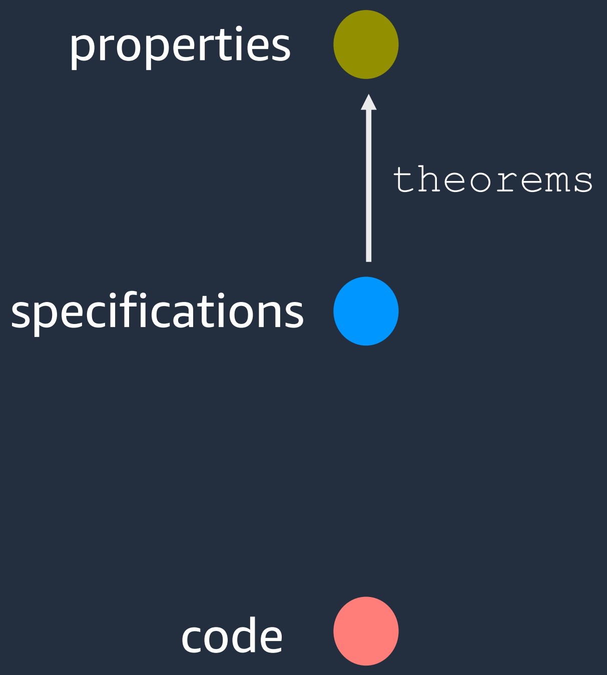

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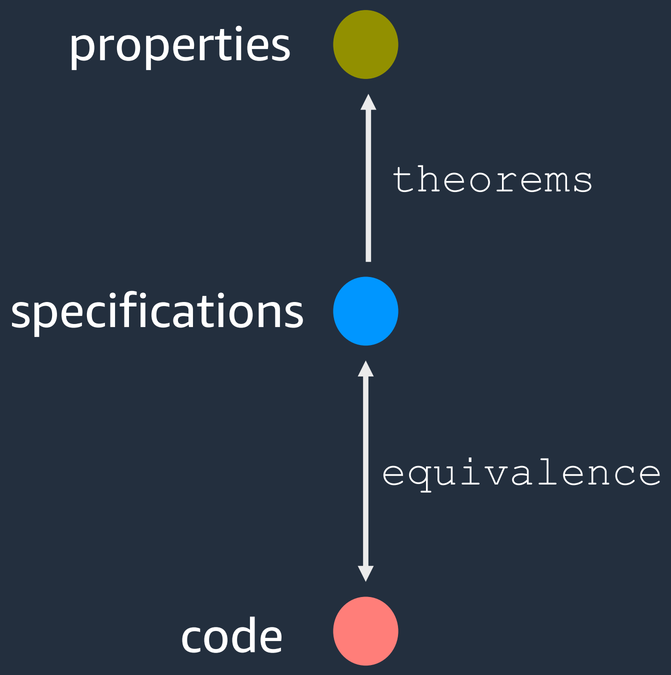

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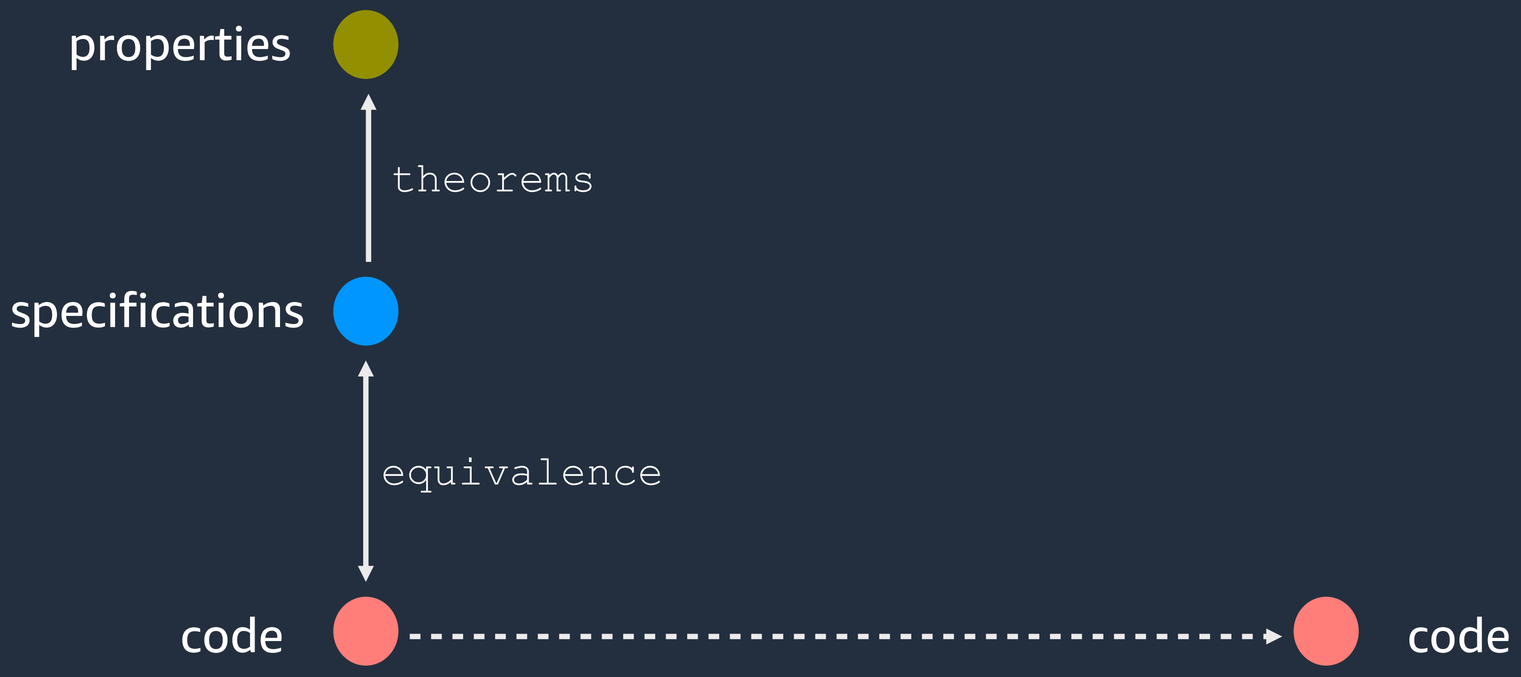

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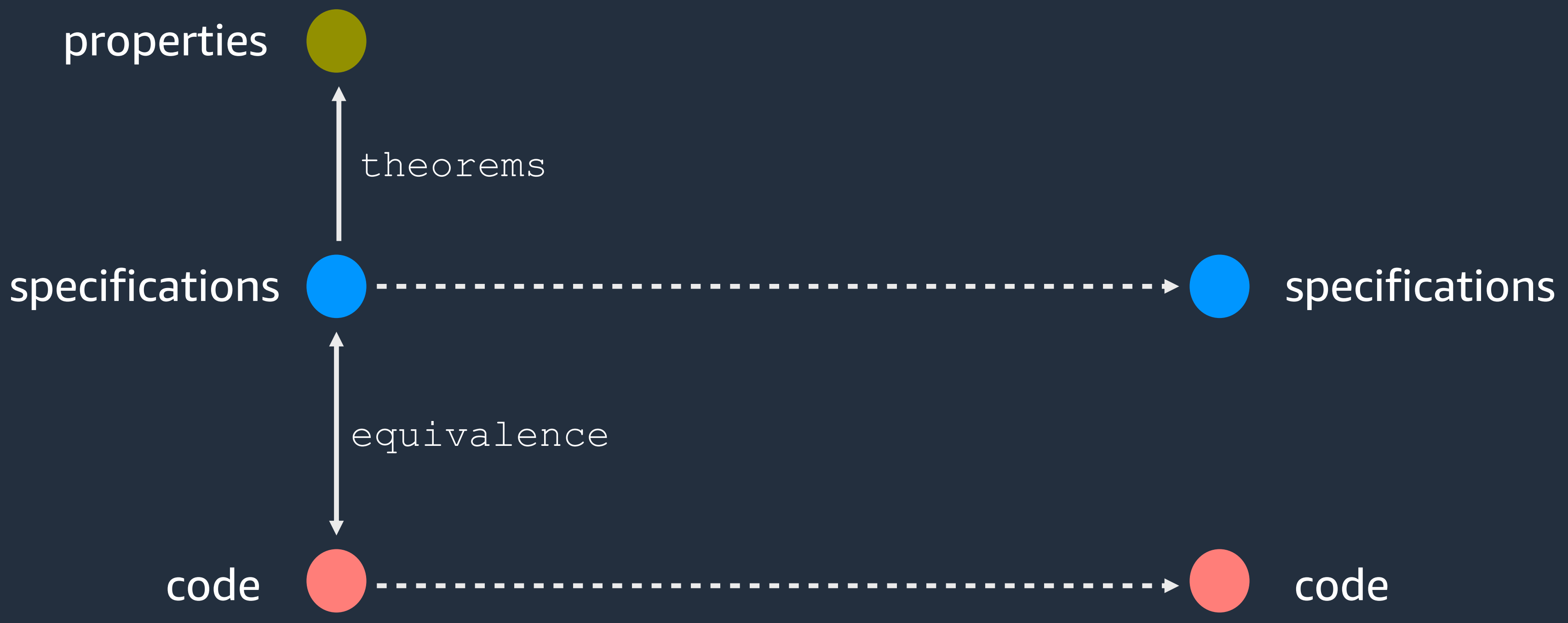

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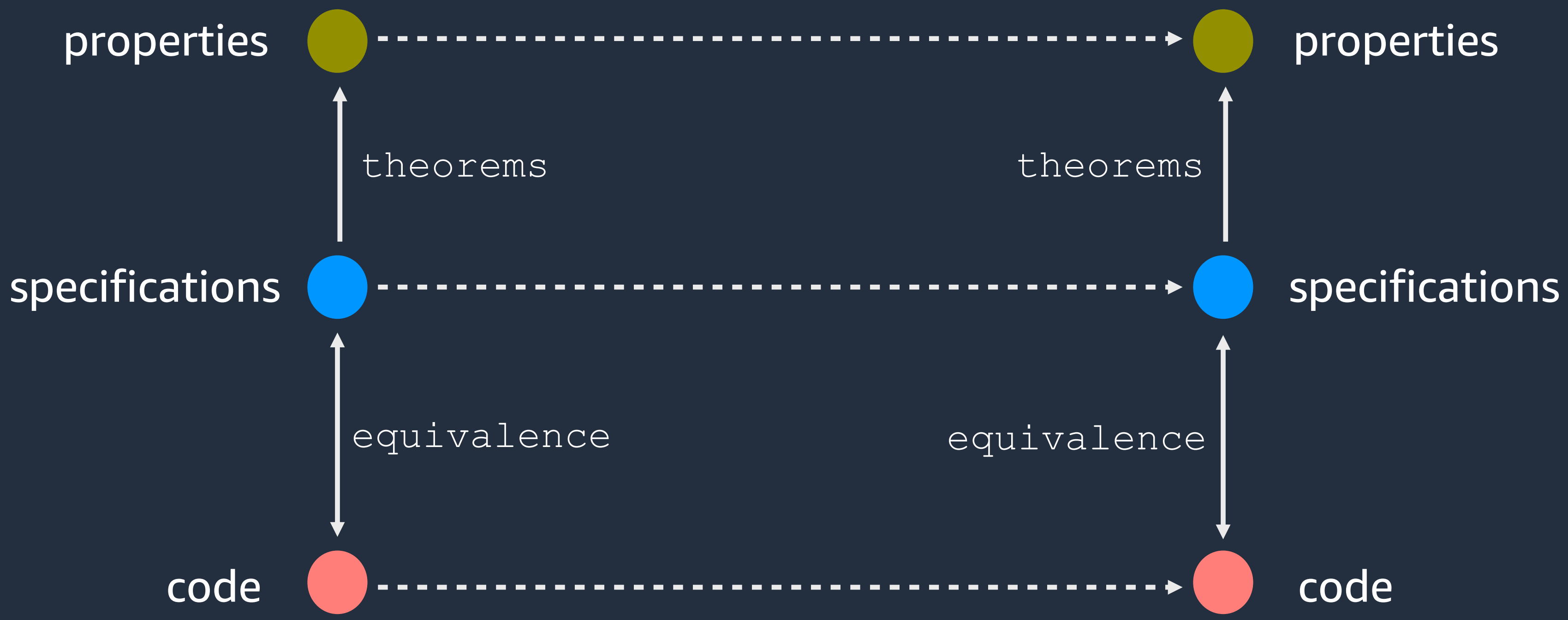

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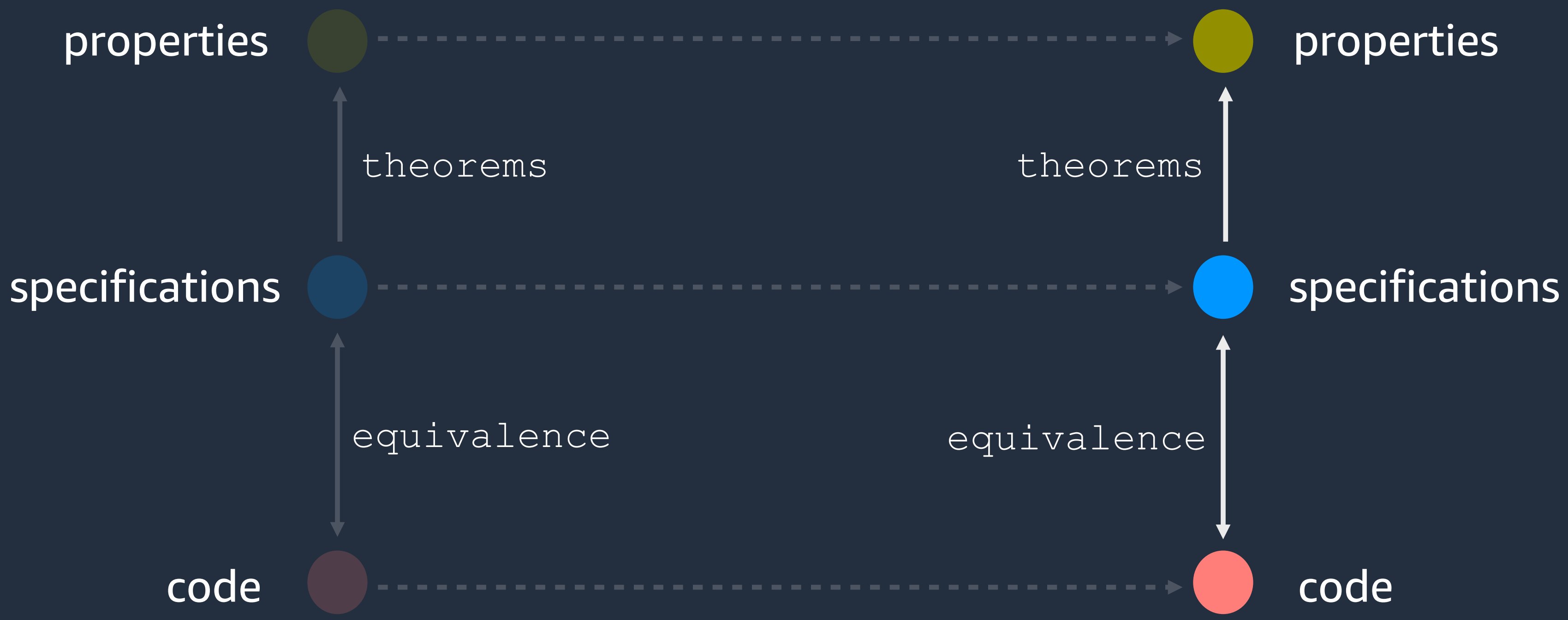

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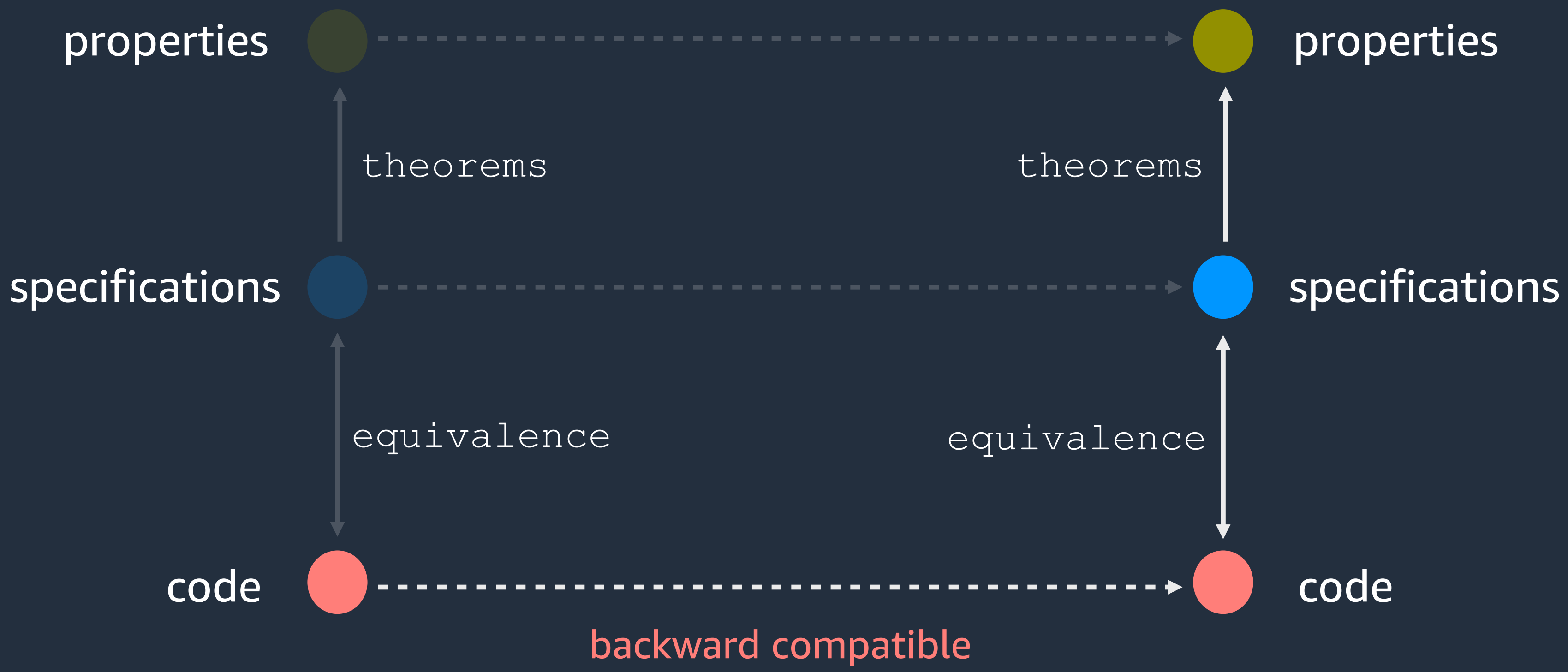

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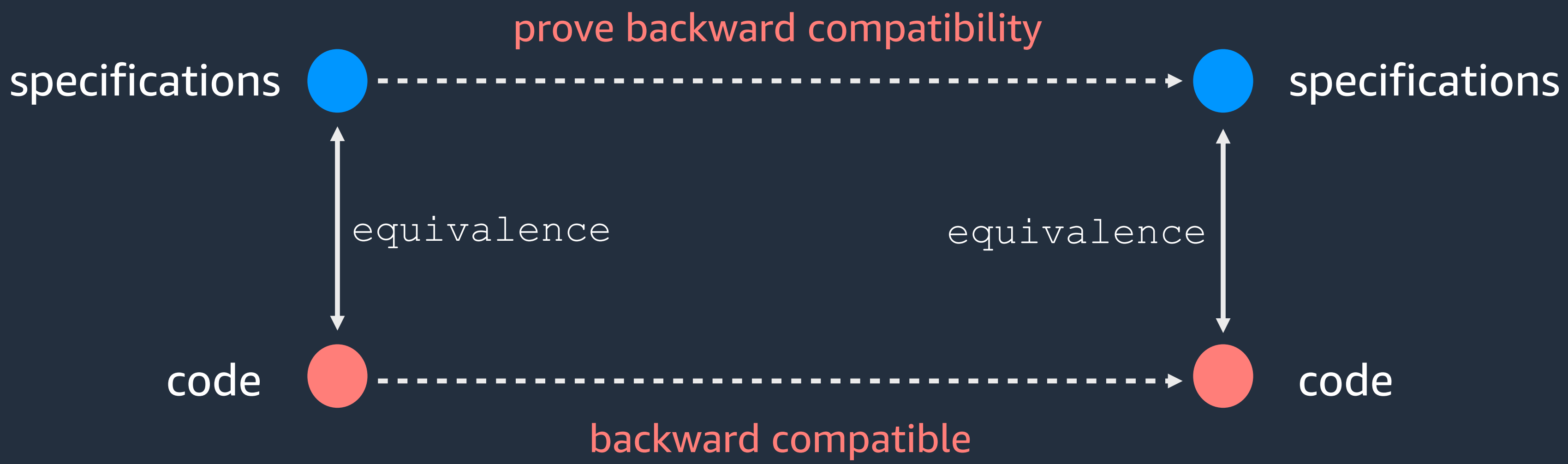

Verification is an Achievement

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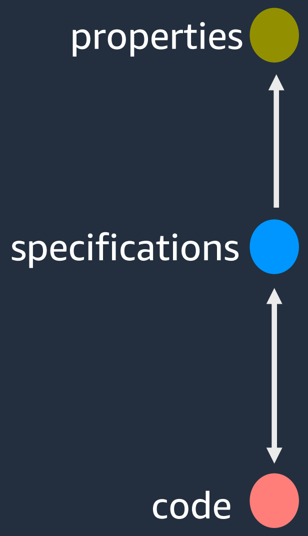

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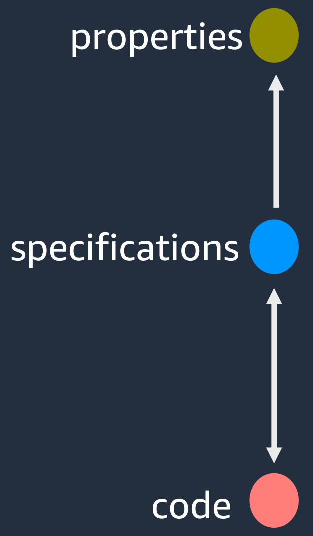

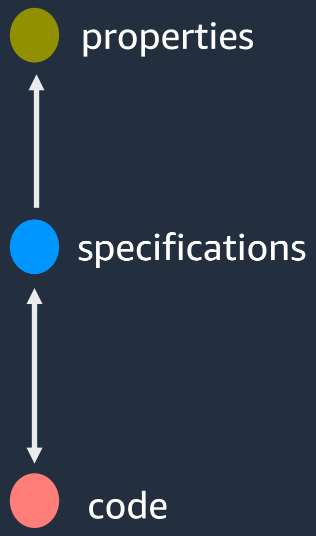

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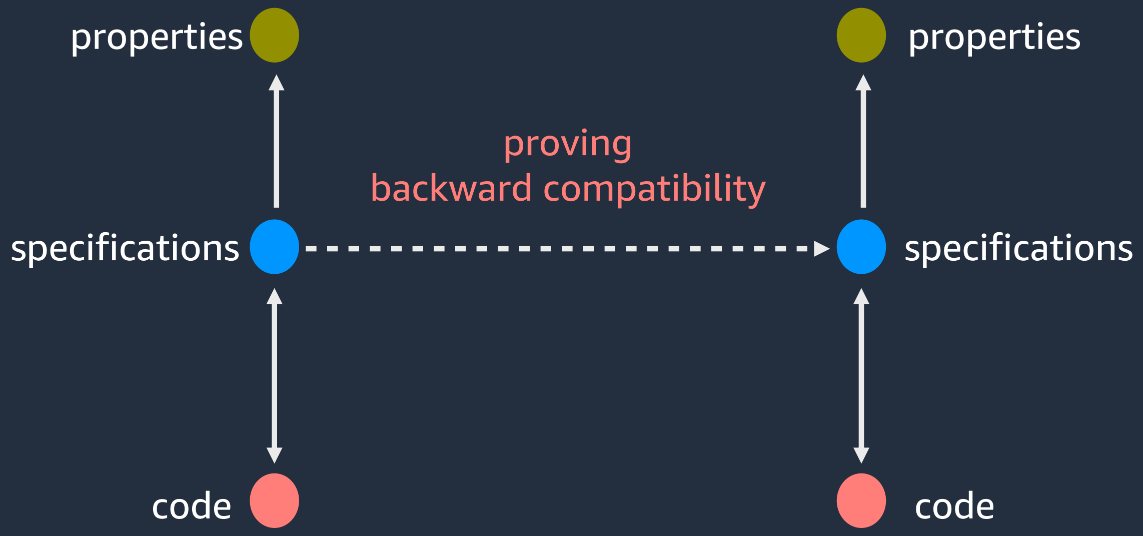

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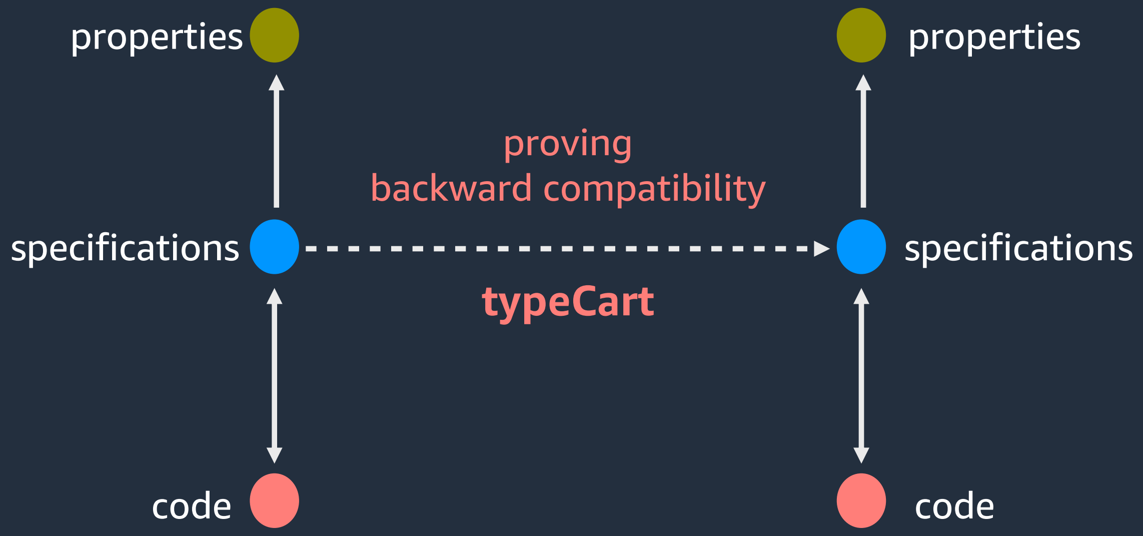
- typeCart: automates the process of relating specifications



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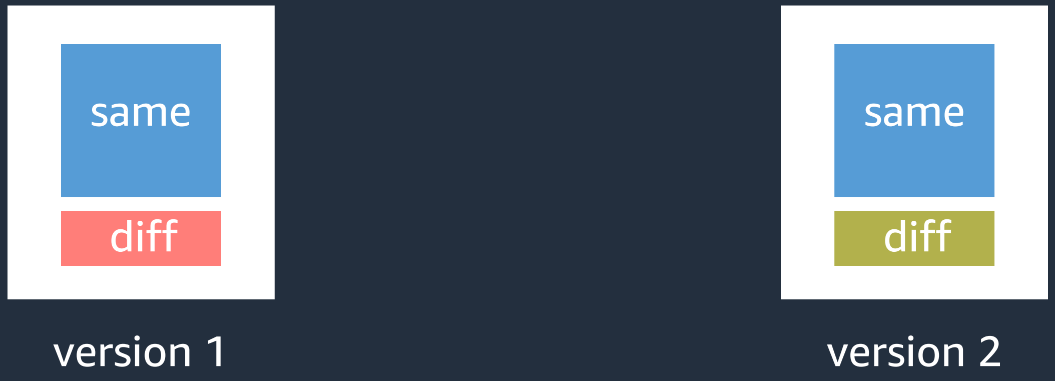

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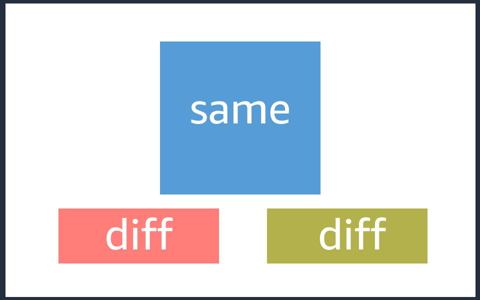
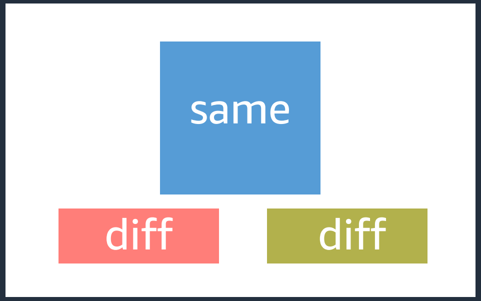


version 1 and version 2

Is Relating any Two Specifications Difficult?

- Relating equivalent objects between specifications should be trivial
- Let's test our hypothesis!



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Reasoning about Deltas

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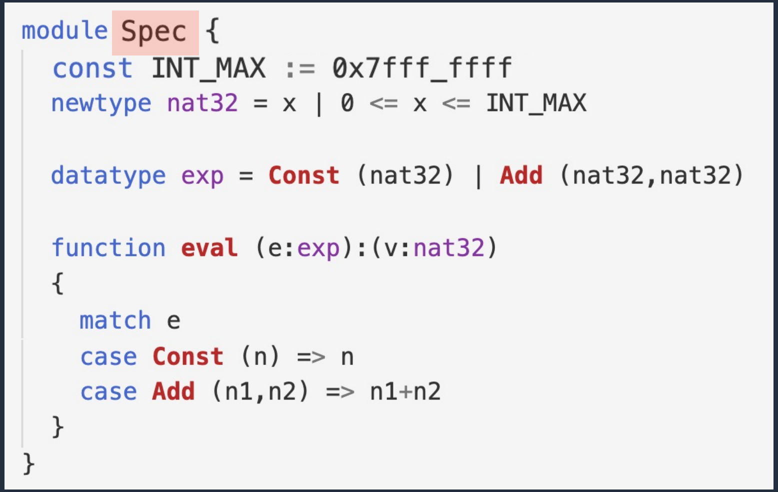

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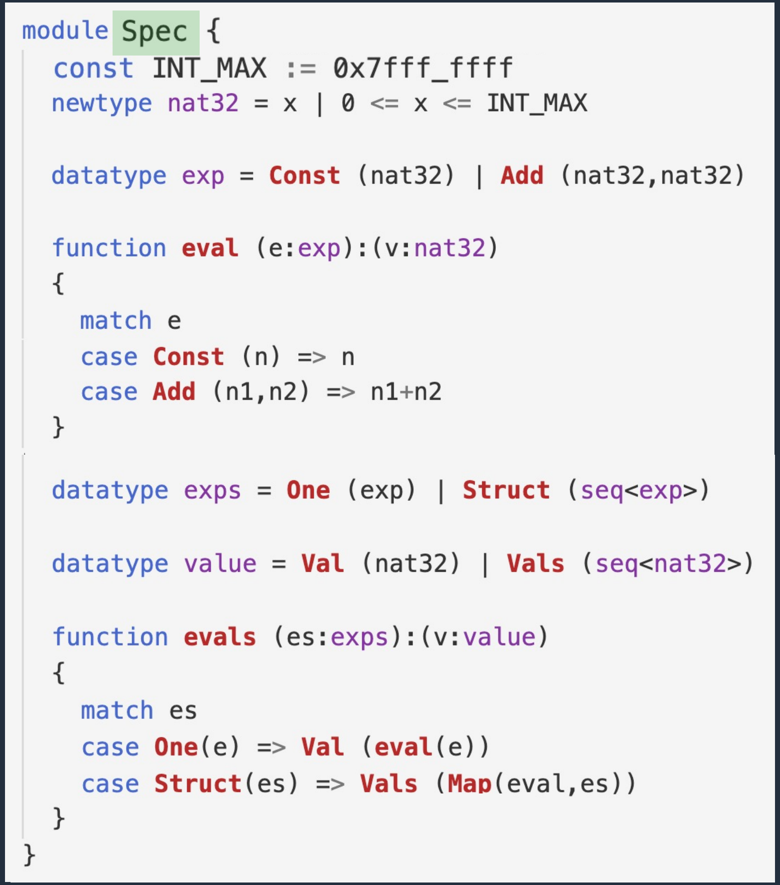

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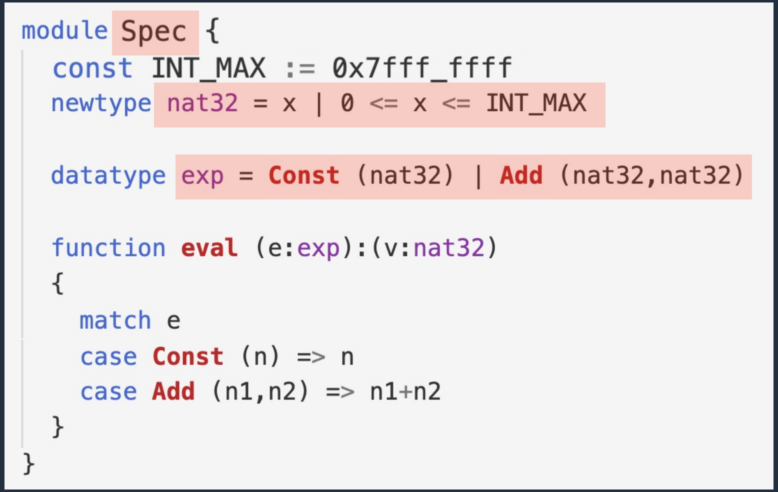

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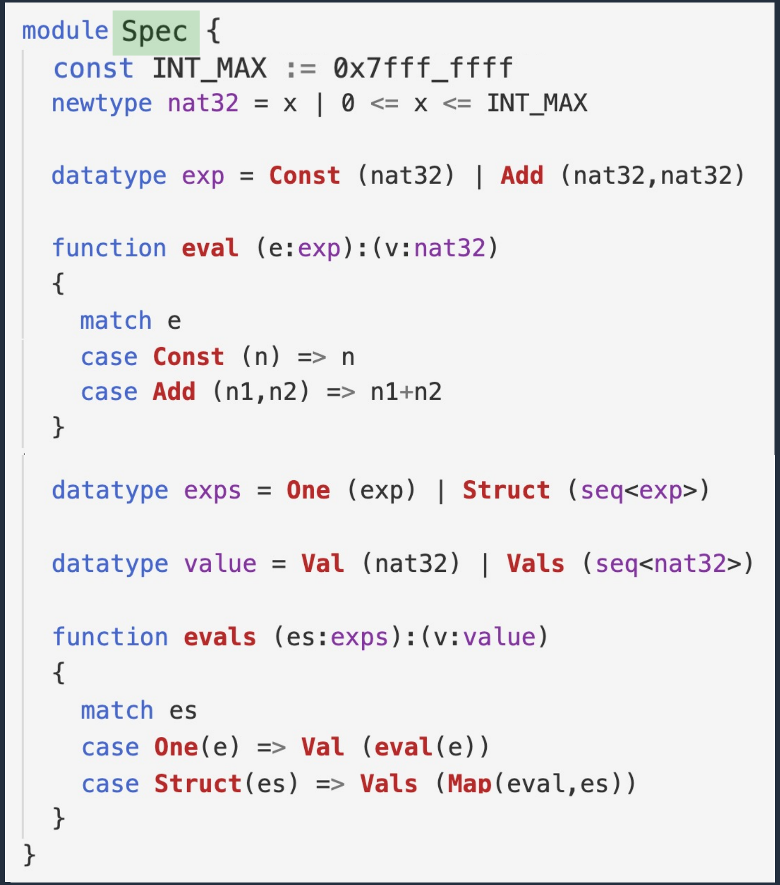

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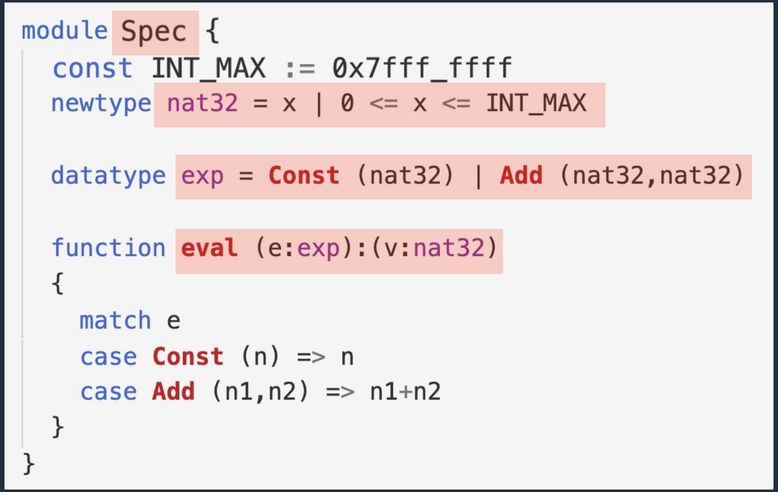

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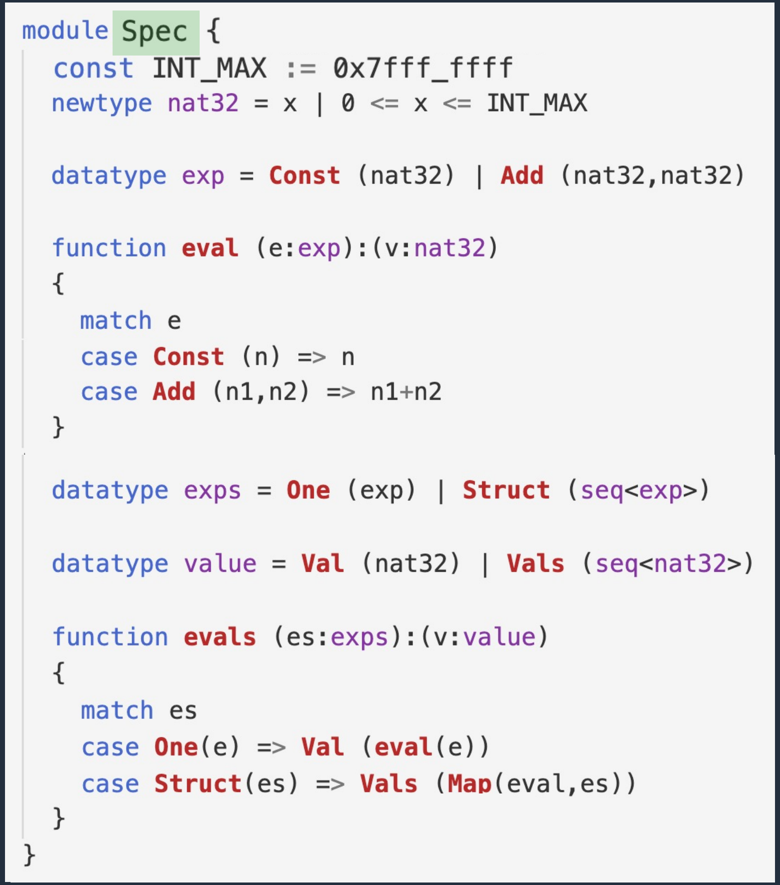

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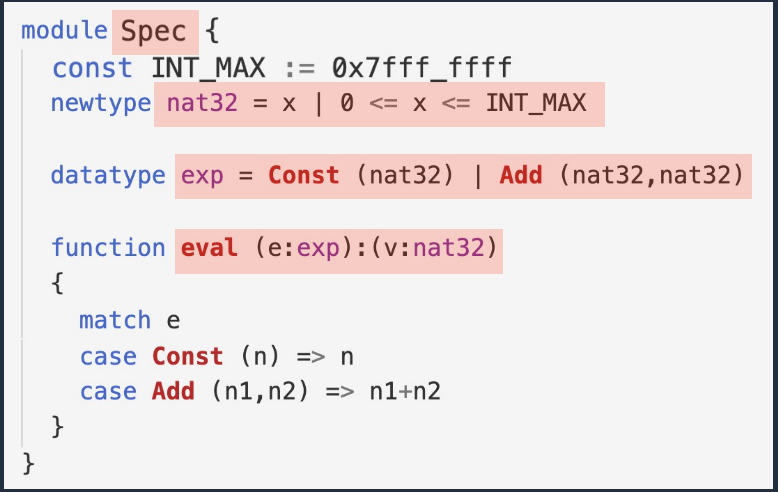

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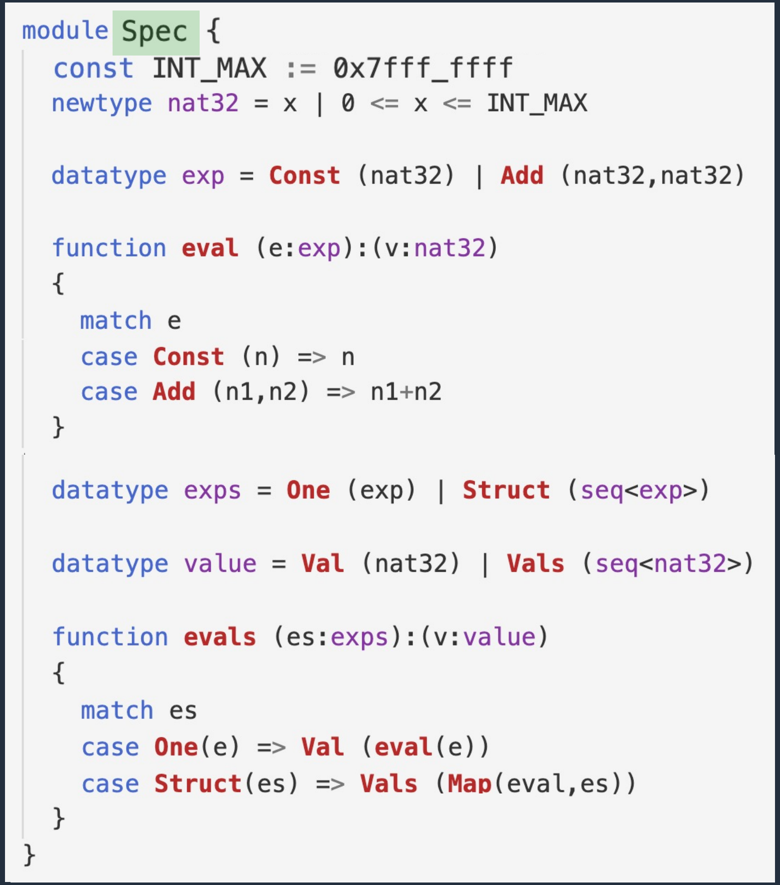

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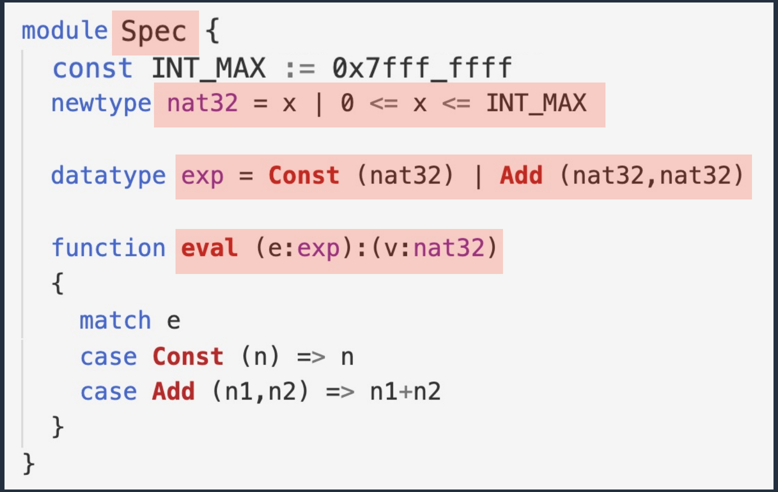

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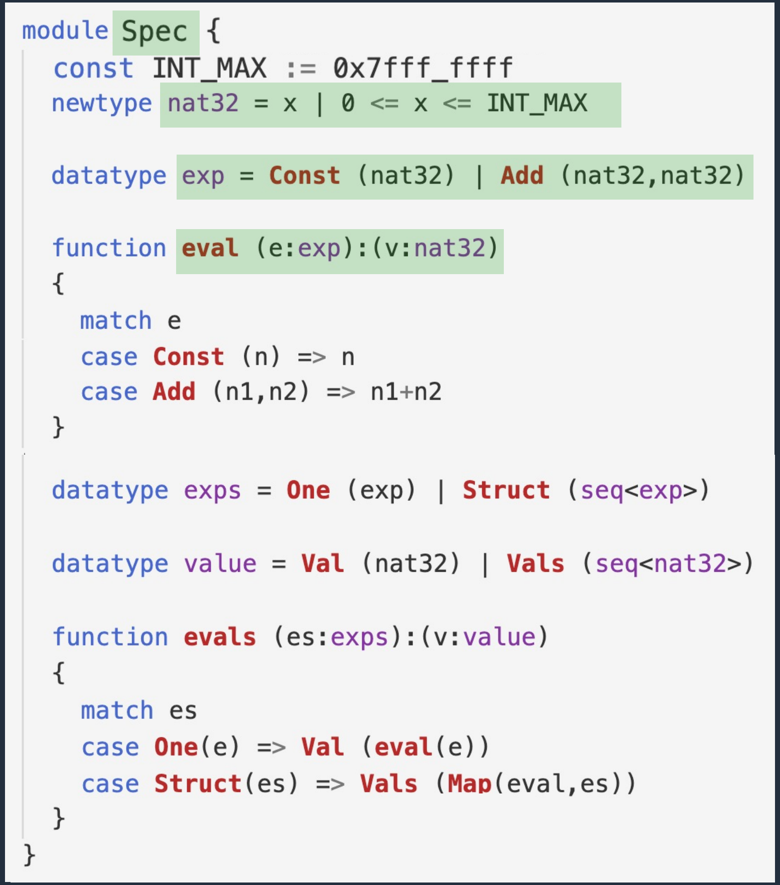

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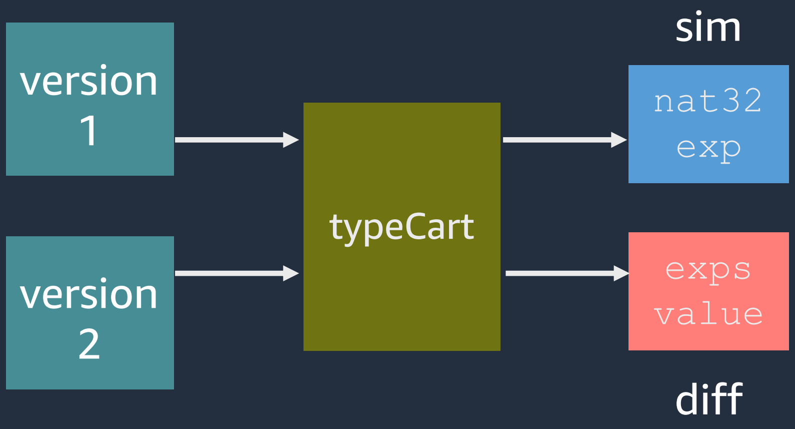

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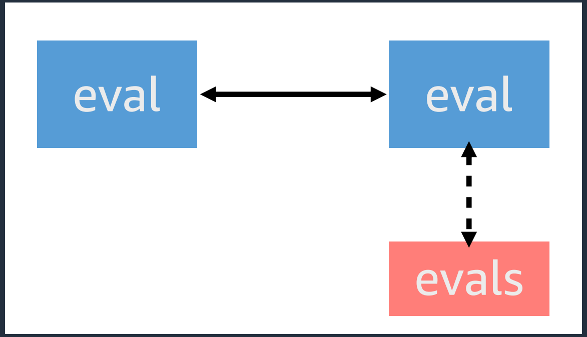

backward compatibility

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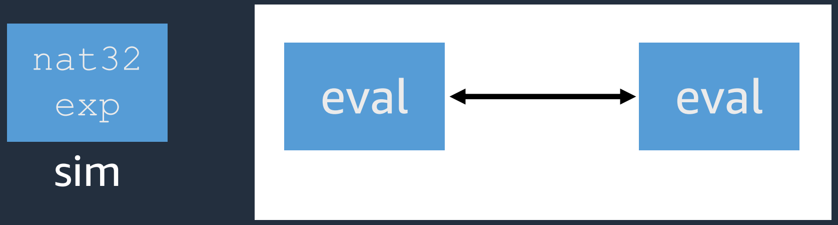
both `eval` functions evaluate to the same answer



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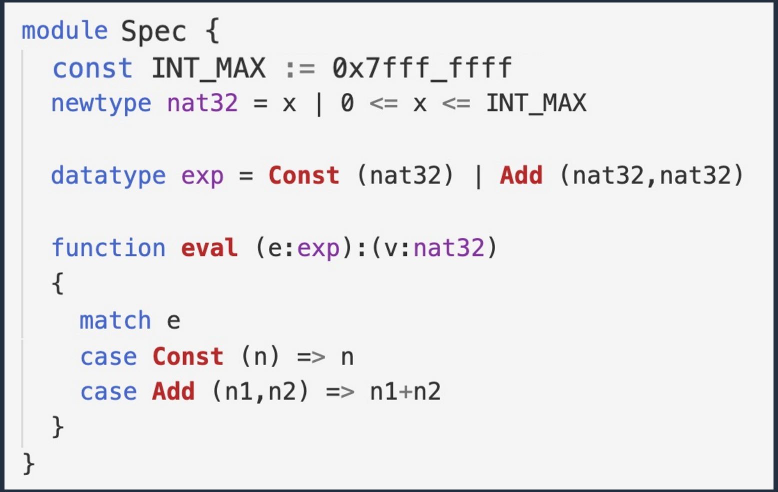

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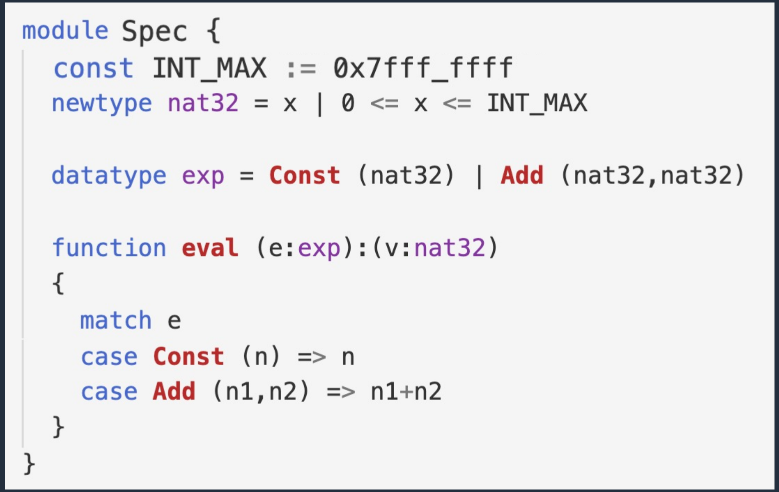

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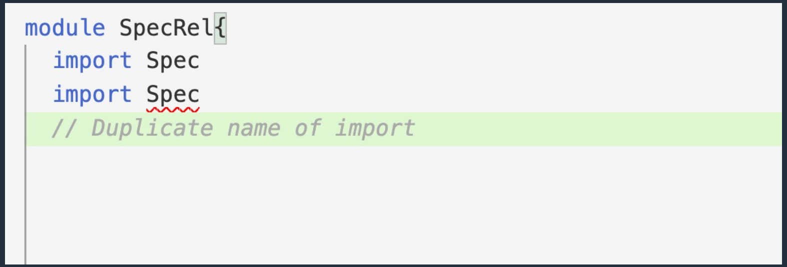

```
module SpecRel{
  import Spec
  import Spec
  // Duplicate name of import
```

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}
```

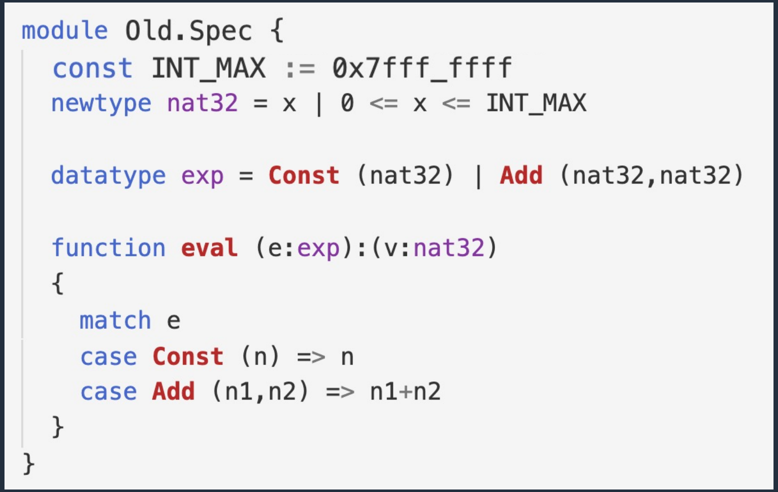
<u>both `eval` functions evaluate to the same answer</u>

namespaces for different versions

```
module SpecRel{
  import Old
  import New
```

Reasoning about Deltas

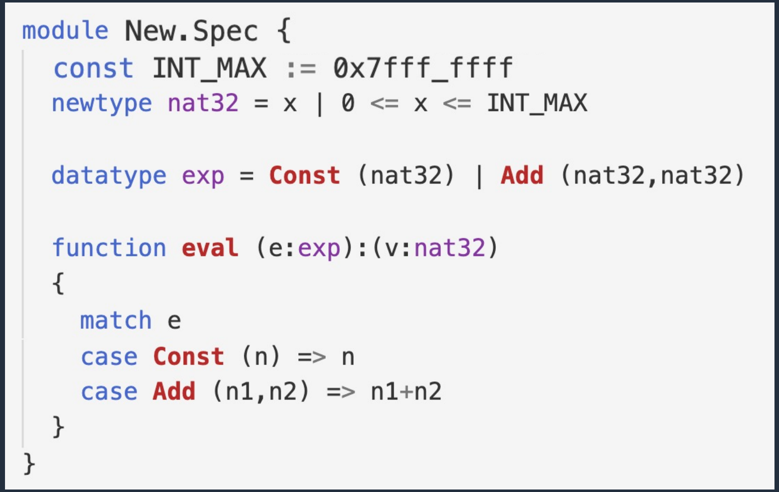
- Relating equivalent objects between specifications should be trivial



```
module Old.Spec {
  const INT_MAX := 0x7fff_ffff
  newtype nat32 = x | 0 <= x <= INT_MAX

  datatype exp = Const (nat32) | Add (nat32,nat32)

  function eval (e:exp):(v:nat32)
  {
    match e
    case Const (n) => n
    case Add (n1,n2) => n1+n2
  }
}
```



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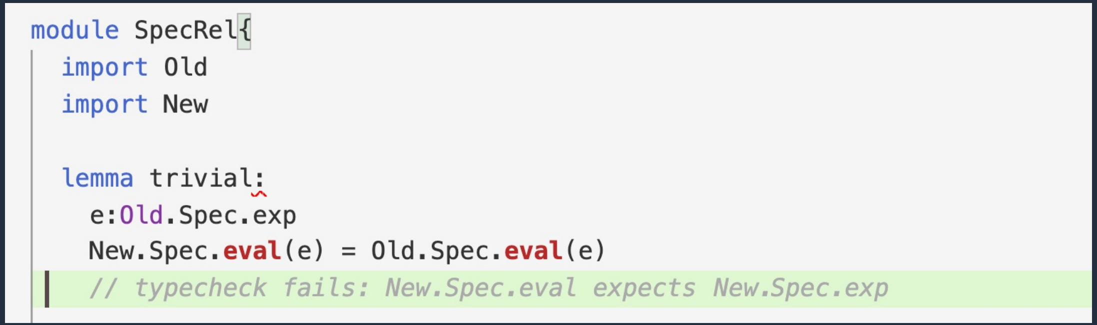
}
```



```
module SpecRel{
  import Old
  import New

  lemma trivial:
    e:Old.Spec.exp
    New.Spec.eval(e) = Old.Spec.eval(e)
    // typecheck fails: New.Spec.eval expects New.Spec.exp
```

Reasoning about Deltas

- Relating equivalent objects between specifications should be trivial

```
module Old.Spec {
  const INT_MAX := 0x7fff_ffff
  newtype nat32 = x | 0 <= x <= INT_MAX

  datatype exp = Const (nat32) | Add (nat32,nat32)

  function eval (e:exp):(v:nat32)
  {
    match e
    case Const (n) => n
    case Add (n1,n2) => n1+n2
  }
}
```

```
module New.Spec {
  const INT_MAX := 0x7fff_ffff
  newtype nat32 = x | 0 <= x <= INT_MAX

  datatype exp = Const (nat32) | Add (nat32,nat32)

  function eval (e:exp):(v:nat32)
  {
    match e
    case Const (n) => n
    case Add (n1,n2) => n1+n2
  }
}
```

type casting
functions

```
module SpecRel{
  import Old
  import New

  lemma trivial:
   New.Spec.eval(expOldtoNew(e)) = Old.Spec.eval(e)
  // typecheck fails: New.Spec.nat32 and Old.Spec.nat32
```

Reasoning about Deltas

- Relating equivalent objects between specifications should be trivial

```
module Old.Spec {
  const INT_MAX := 0x7fff_ffff
  newtype nat32 = x | 0 <= x <= INT_MAX

  datatype exp = Const (nat32) | Add (nat32,nat32)

  function eval (e:exp):(v:nat32)
  {
    match e
    case Const (n) => n
    case Add (n1,n2) => n1+n2
  }
}
```

```
module New.Spec {
  const INT_MAX := 0x7fff_ffff
  newtype nat32 = x | 0 <= x <= INT_MAX

  datatype exp = Const (nat32) | Add (nat32,nat32)

  function eval (e:exp):(v:nat32)
  {
    match e
    case Const (n) => n
    case Add (n1,n2) => n1+n2
  }
}
```

type casting functions

```
module SpecRel{
  import Old
  import New

  lemma trivial:
    New.Spec.eval(expOldtoNew(e)) = nat32OldtoNew(Old.Spec.eval(e))
    // typecheck succeeds
```

Reasoning about Deltas

- Hypothesis: relating equivalent objects between specifications should be trivial
  - Yes, but only with type injections (mapping functions)

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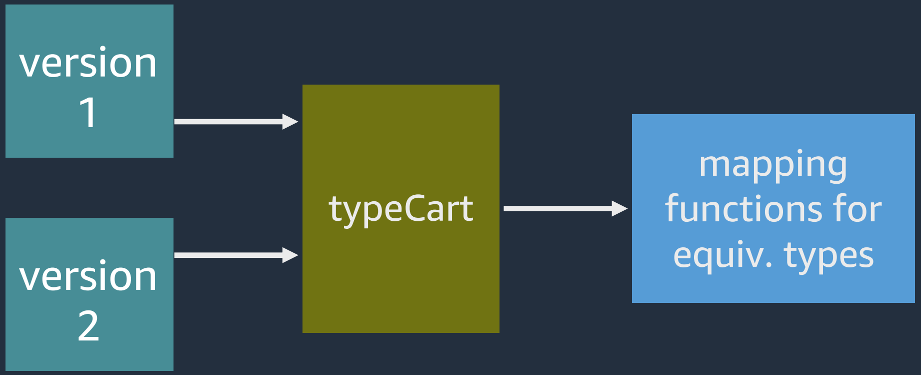

Reasoning about Deltas

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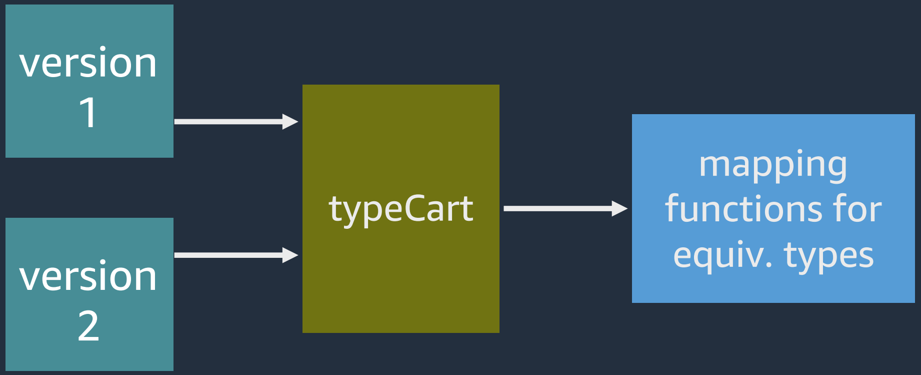
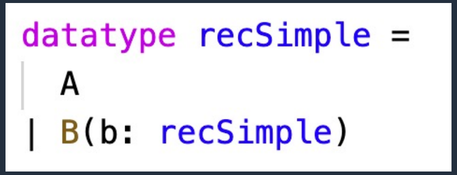


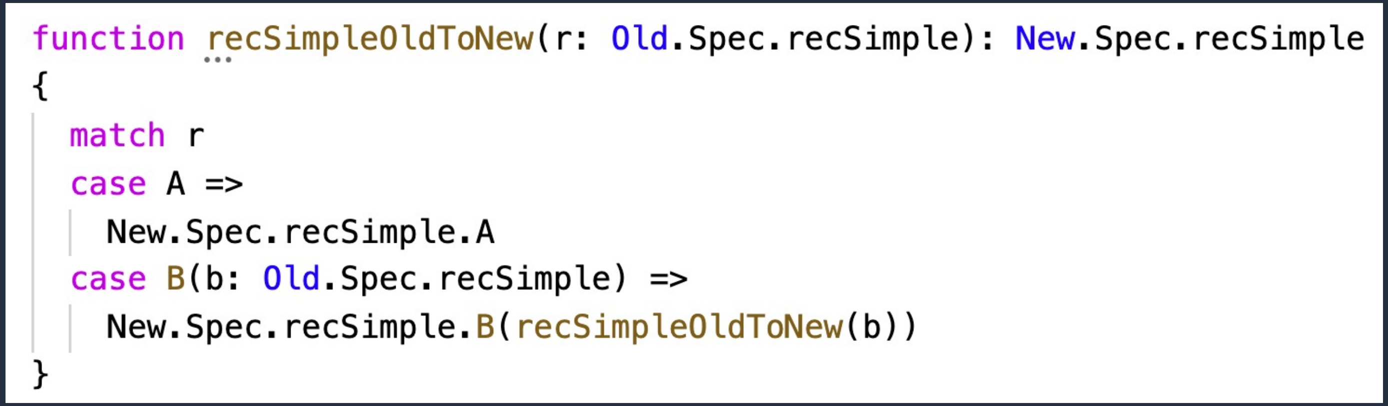
Fun Fact
typeCart: name-blend of **type** and **cartography** (practice of making maps)

typeCart — Examples

- Recursive datatype



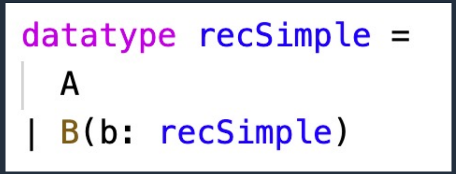
```
datatype recSimple =
    A
  | B(b: recSimple)
```



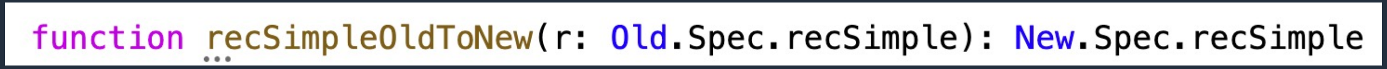
```
function recSimpleOldToNew(r: Old.Spec.recSimple): New.Spec.recSimple
{
  match r
  case A =>
    New.Spec.recSimple.A
  case B(b: Old.Spec.recSimple) =>
    New.Spec.recSimple.B(recSimpleOldToNew(b))
}
```

typeCart — Examples

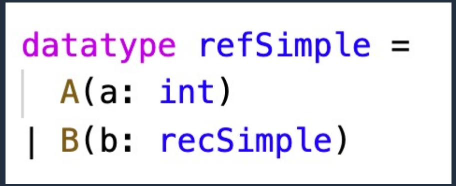
- Recursive datatype



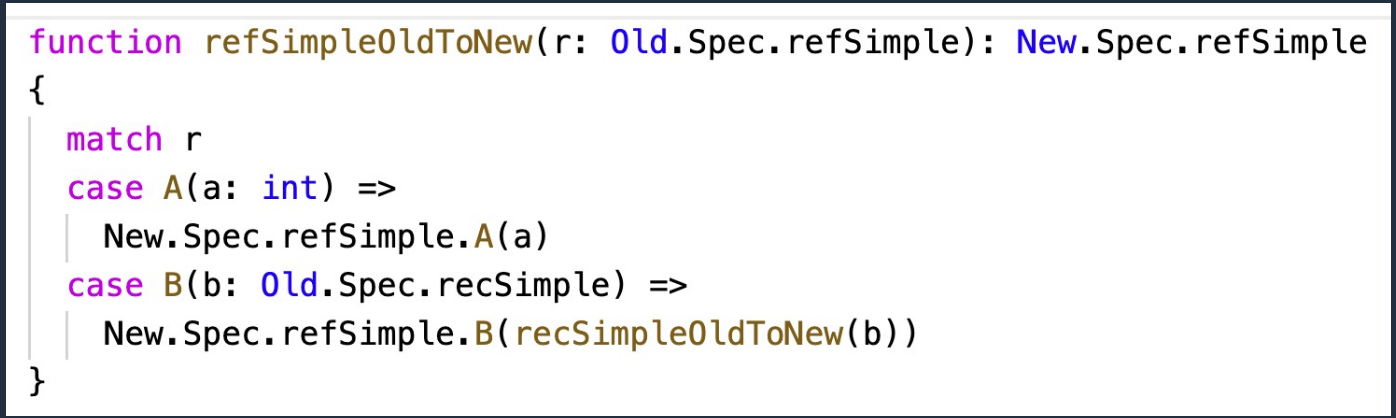
```
datatype recSimple =
  A
| B(b: recSimple)
```



```
function recSimpleOldToNew(r: Old.Spec.recSimple): New.Spec.recSimple
```



```
datatype refSimple =
  A(a: int)
| B(b: recSimple)
```



```
function refSimpleOldToNew(r: Old.Spec.refSimple): New.Spec.refSimple
{
  match r
  case A(a: int) =>
    New.Spec.refSimple.A(a)
  case B(b: Old.Spec.recSimple) =>
    New.Spec.refSimple.B(recSimpleOldToNew(b))
}
```

- Types that refer others

typeCart — Examples

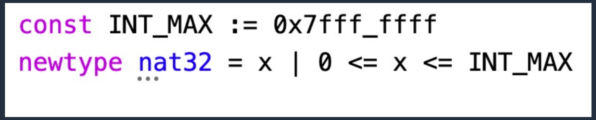
- Parametric types

```
datatype either<S, T> =
  Left(s: S)
| Right (t: T)
```

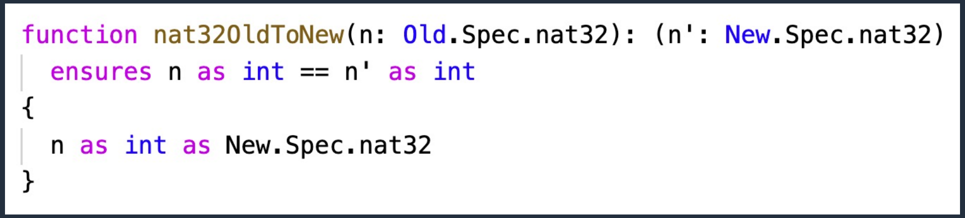
```
function eitherOldToNew<S, T, S', T'>
  (fS: S -> S', fT: T -> T', e: Old.Spec.either<S, T>):
  New.Spec.either<S', T'>
{
  match e
  case Left(s: S) =>
    New.Spec.either.Left(fS(s))
  case Right(t: T) =>
    New.Spec.either.Right(fT(t))
}
```

typeCart — Examples

- Bounded types



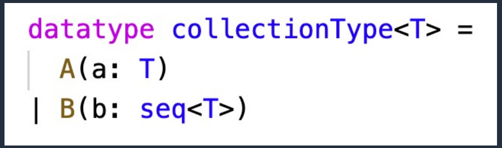
```
const INT_MAX := 0x7fff_ffff
newtype nat32 = x | 0 <= x <= INT_MAX
```



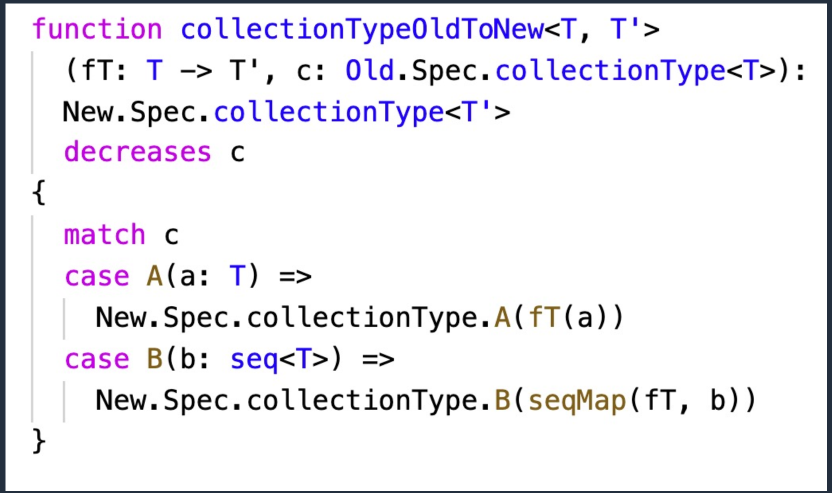
```
function nat32OldToNew(n: Old.Spec.nat32): (n': New.Spec.nat32)
  ensures n as int == n' as int
{
  n as int as New.Spec.nat32
}
```

typeCart — Examples

- Collection types

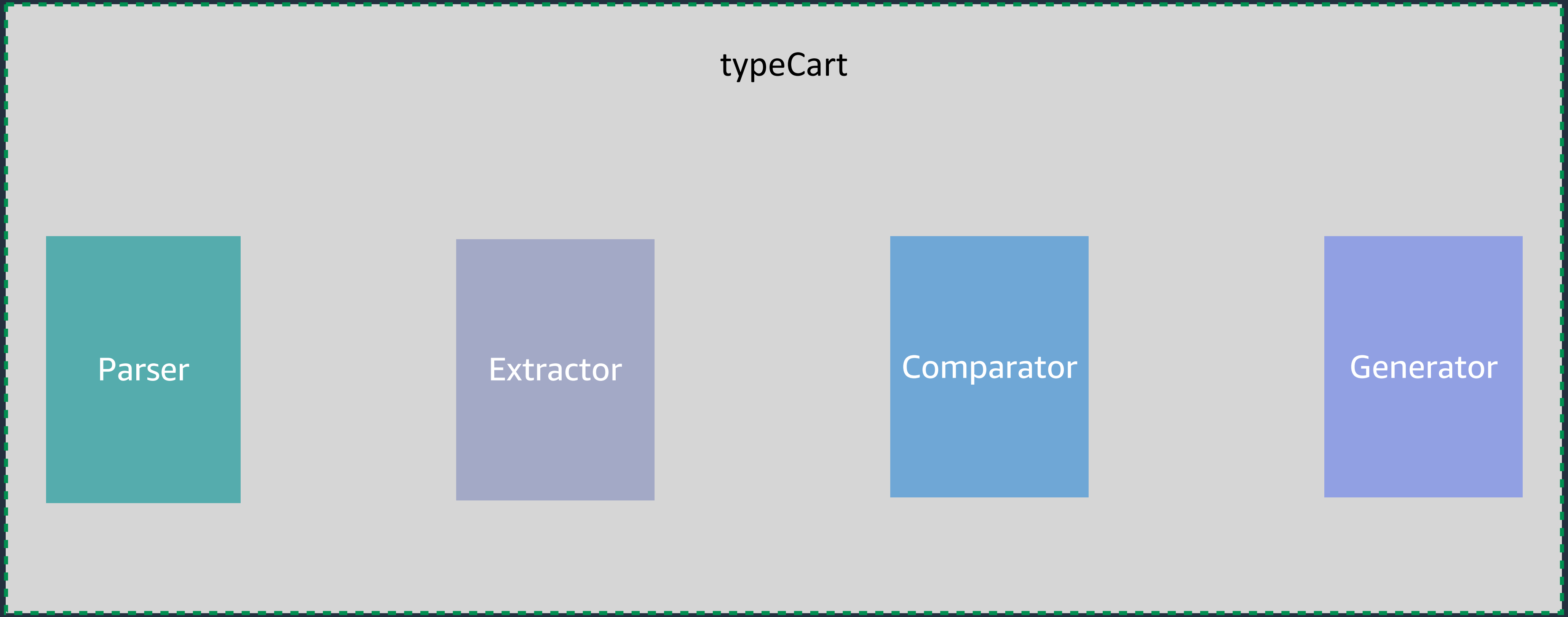


```
datatype collectionType<T> =
    A(a: T)
  | B(b: seq<T>)
```



```
function collectionTypeOldToNew<T, T'>
  (fT: T -> T', c: Old.Spec.collectionType<T>):
  New.Spec.collectionType<T'>
  decreases c
{
  match c
  case A(a: T) =>
    New.Spec.collectionType.A(fT(a))
  case B(b: seq<T>) =>
    New.Spec.collectionType.B(seqMap(fT, b))
}
```

typeCart — Architecture



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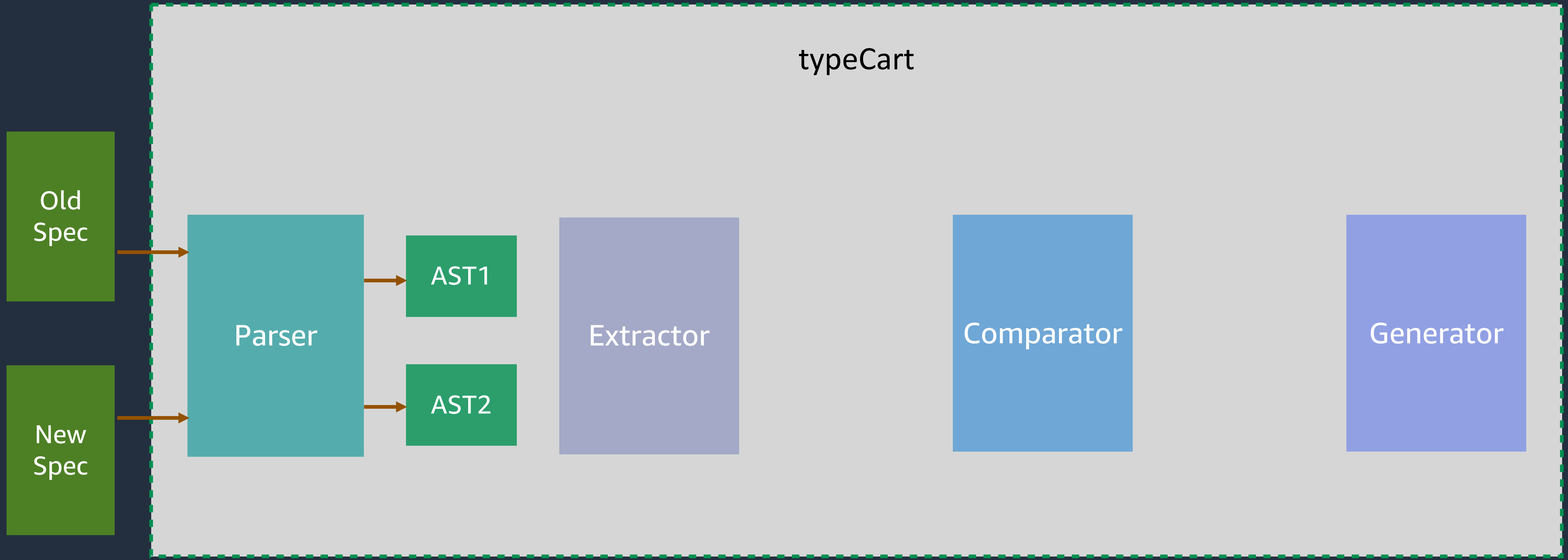

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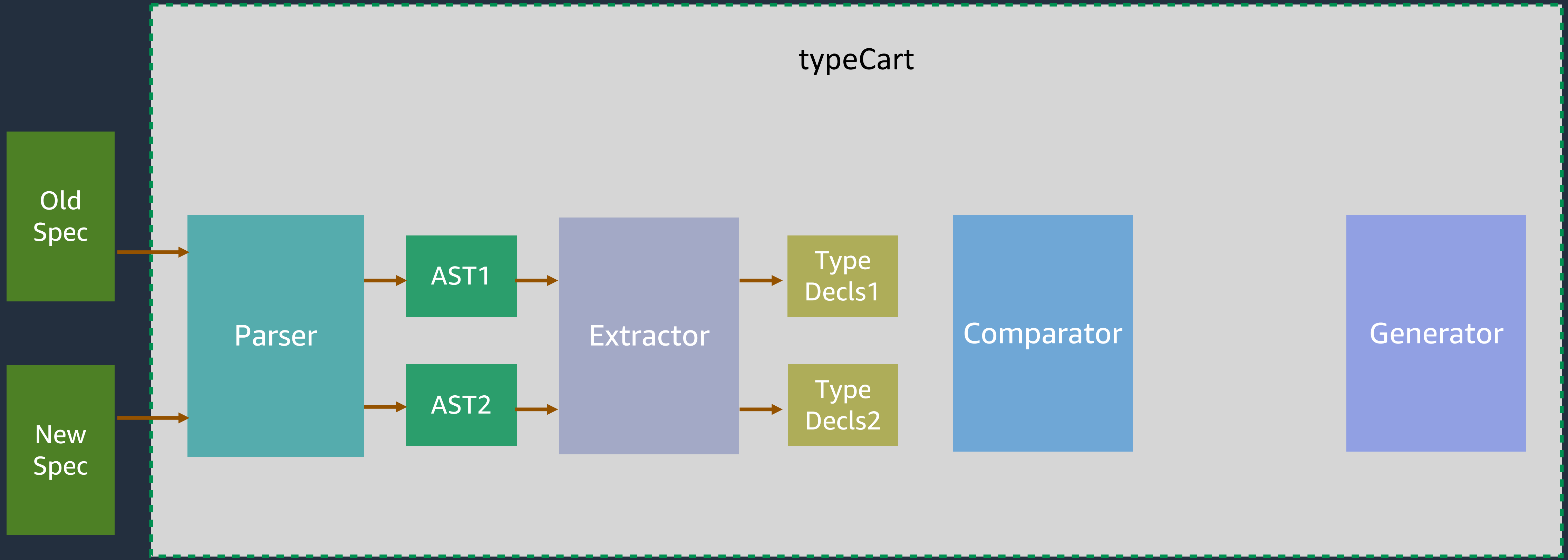
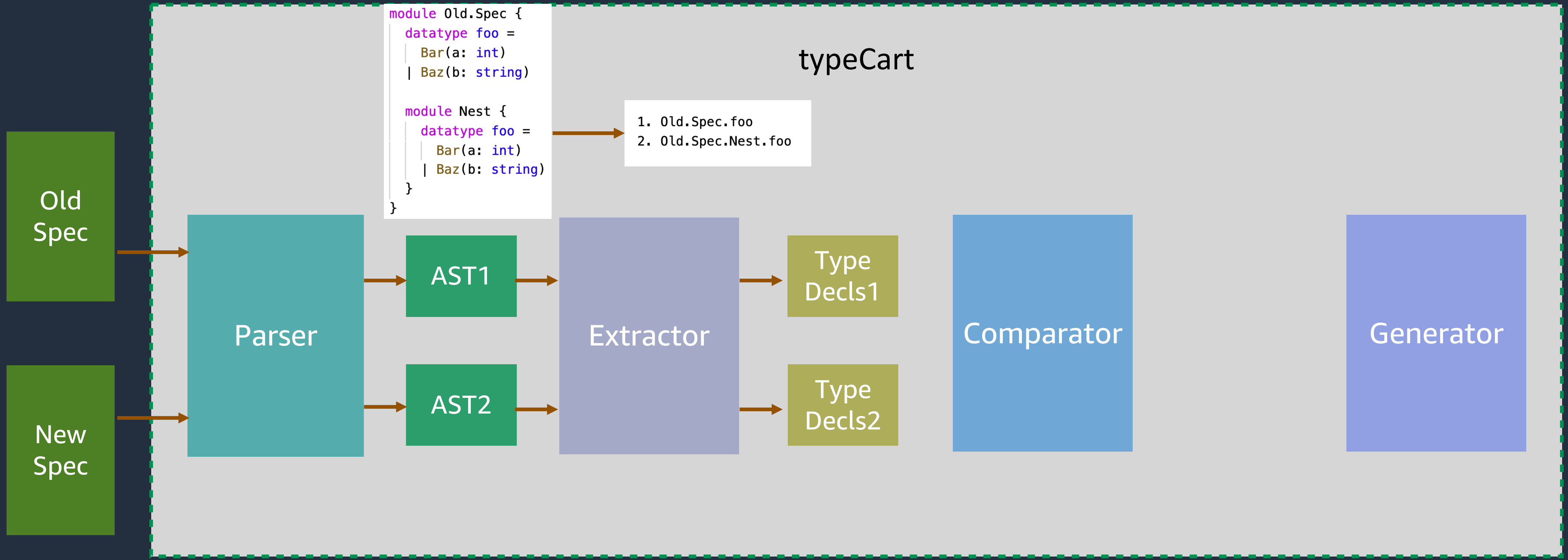


typeCart — Architecture

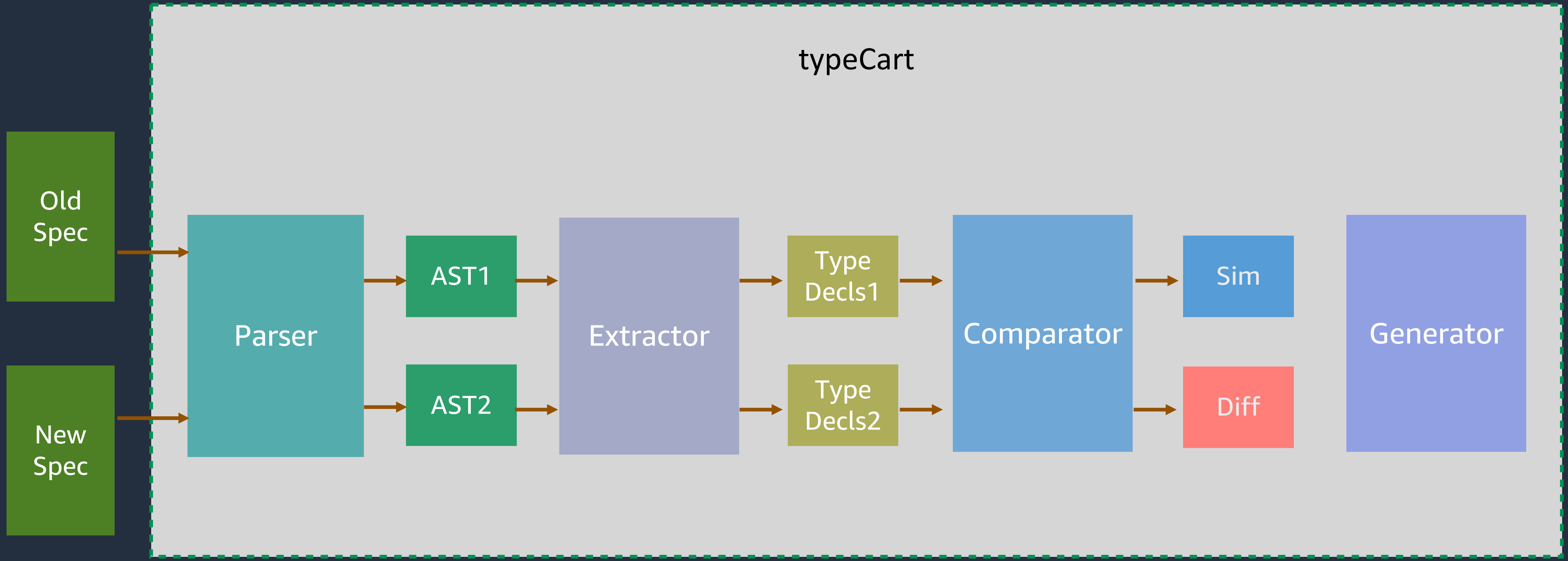


```
module Old.Spec {
  datatype foo =
    Bar(a: int)
  | Baz(b: string)

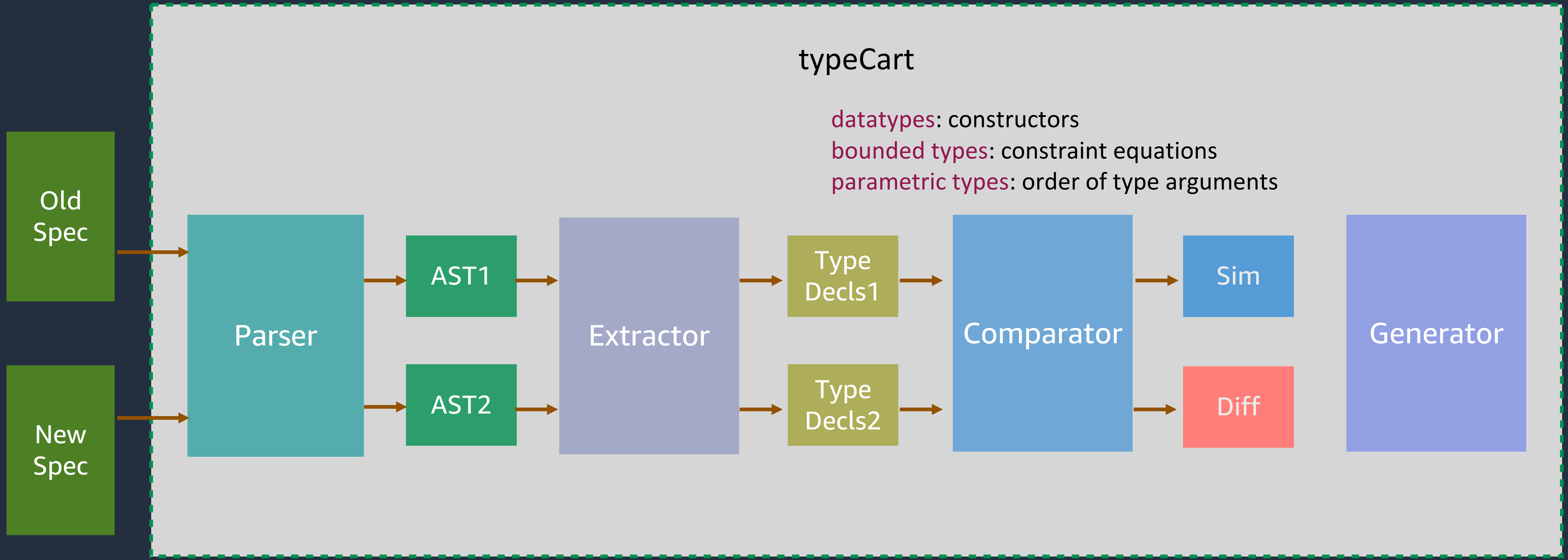
  module Nest {
    datatype foo =
      Bar(a: int)
    | Baz(b: string)
  }
}
```

```
1. Old.Spec.foo
2. Old.Spec.Nest.foo
```

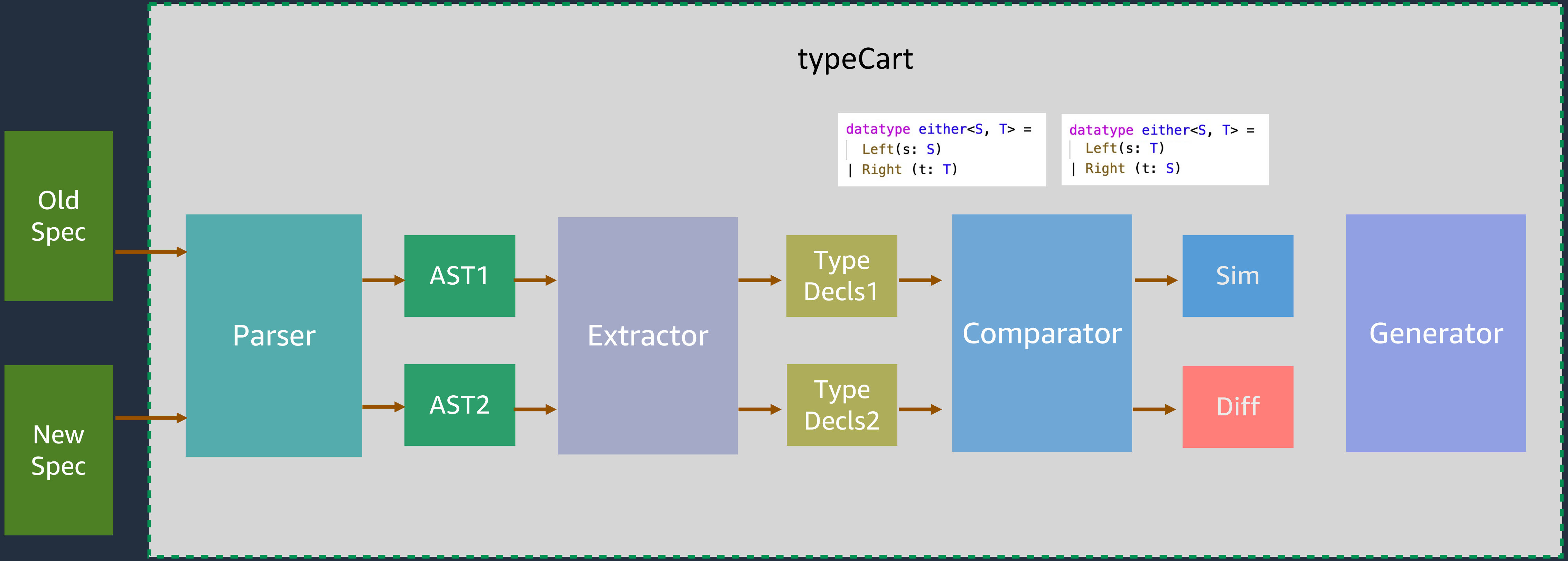
typeCart — Architecture



typeCart — Architecture



typeCart — Architecture



```
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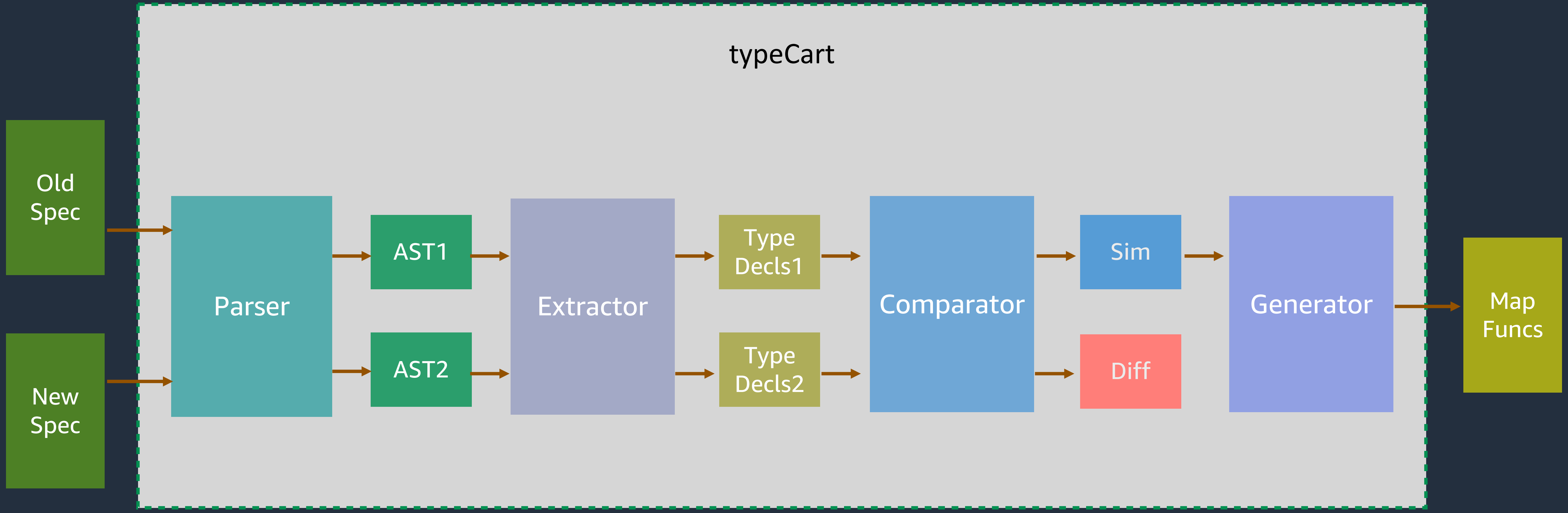
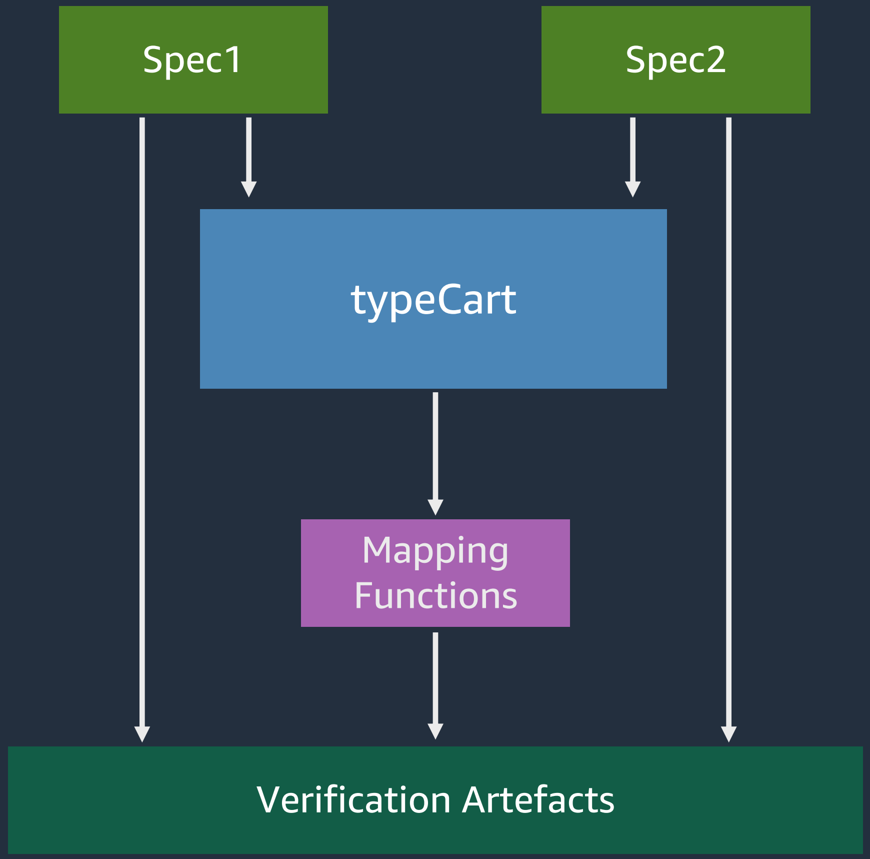
typeCart — Architecture



Integrating typeCart to Verification



Recap

```
datatype exp = Const (nat32) | Add (nat32,nat32)

function eval (e:exp):(v:nat32)
```

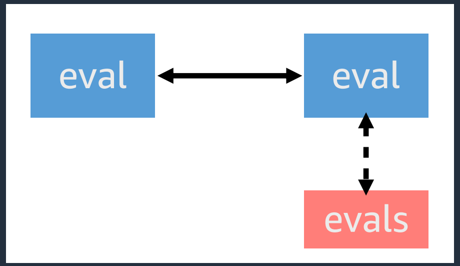
version1

```
datatype exps = One (exp) | Struct (seq<exp>)

datatype value = Val (nat32) | Vals (seq<nat32>)

function evals (es:exps):(v:value)
```

version2



backward compatibility

Recap

```
datatype exp = Const (nat32) | Add (nat32,nat32)

function eval (e:exp):(v:nat32)
```

version1

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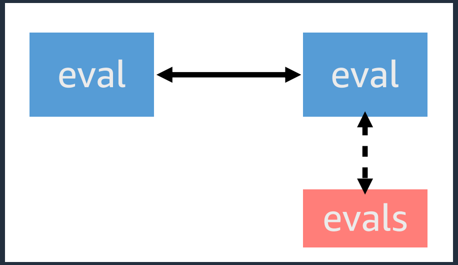
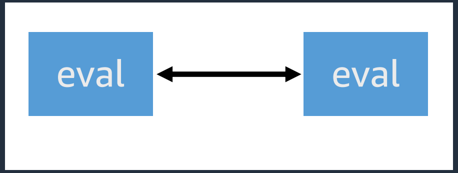
function evals (es:exps):(v:value)
```

version2



backward compatibility

- Doing nothing ~~is~~ was difficult: typeCart



typeCart — Work in Progress

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datatype exp = Const (nat32) | Add (nat32,nat32)

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```

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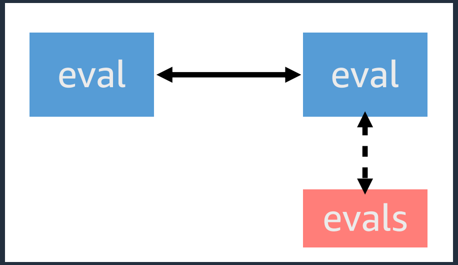
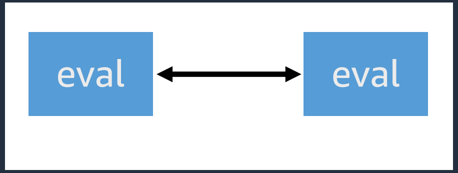
```

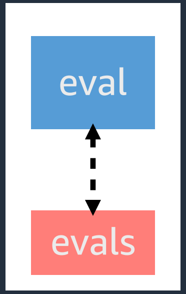
version2



backward compatibility

- Doing nothing ~~is~~ was difficult: typeCart
- Let's do something!
    - Reasoning about deltas





typeCart — Work in Progress

- Specifications deltas involve evolving types
- Evolving types require mapping relations instead of mapping functions

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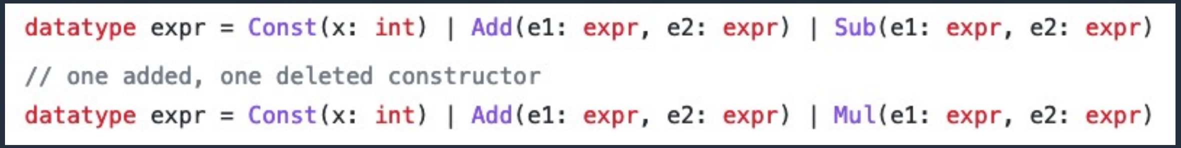
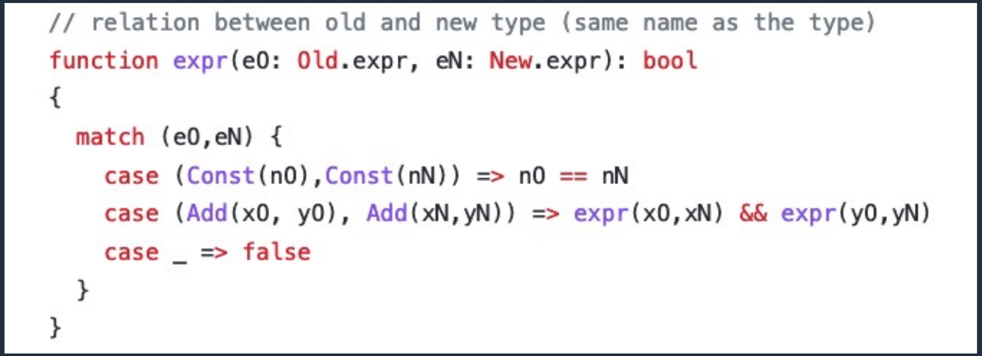


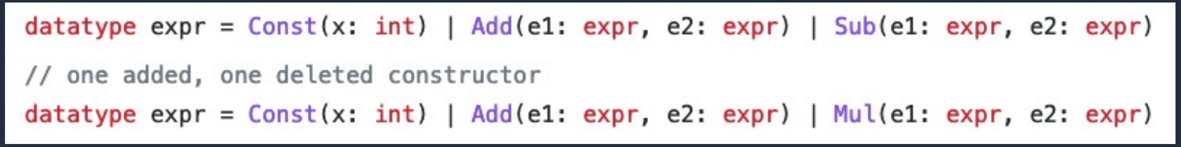
```
datatype expr = Const(x: int) | Add(e1: expr, e2: expr) | Sub(e1: expr, e2: expr)
// one added, one deleted constructor
datatype expr = Const(x: int) | Add(e1: expr, e2: expr) | Mul(e1: expr, e2: expr)
```



```
// relation between old and new type (same name as the type)
function expr(e0: Old.expr, eN: New.expr): bool
{
  match (e0,eN) {
    case (Const(n0),Const(nN)) => n0 == nN
    case (Add(x0, y0), Add(xN,yN)) => expr(x0,xN) && expr(y0,yN)
    case _ => false
  }
}
```

typeCart — Work in Progress

- Specifications deltas involve evolving types
- Evolving types require mapping relations instead of mapping functions



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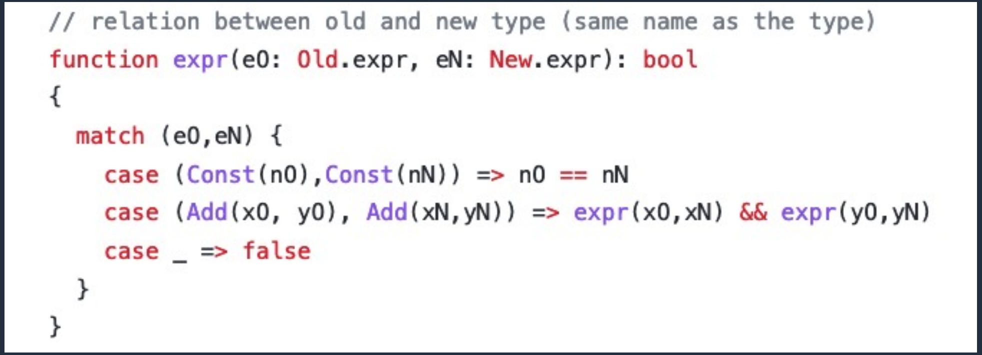

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function expr(eO: Old.expr, eN: New.expr): bool
{
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    case (Add(xO, yO), Add(xN,yN)) => expr(xO,xN) && expr(yO,yN)
    case _ => false
  }
}
```

upcoming typeCart V2:
- will identify evolving+equivalent types
- will generate mapping relations

typeCart — Work in Progress

- Type constructors with higher order arguments require nested translation

typeCart — Work in Progress

- Type constructors with higher order arguments require nested translation

```
datatype foo<A> = Foo (a:A)

datatype bar<A> = Bar (b:foo<foo<A>>)
```

typeCart — Work in Progress

- Type constructors with higher order arguments require nested translation

```
datatype foo<A> = Foo (a:A)

datatype bar<A> = Bar (b:foo<foo<A>>)
```

```
function barOldToNew<A, A'>(fA: A -> A', b: Old.bar<A>): New.bar<A'>
{
  match b
  case Bar(Foo (a)) =>
    New.bar.Bar(New.foo.Foo(fooOldToNew(fA,a)))
}
```

typeCart — Work in Progress

- Generic interface
  - TIL: typeCart Intermediate Language

typeCart — Work in Progress

- Generic interface
  - TIL: typeCart Intermediate Language

- Revision control integration

Backward Compatibility of AWS Authorization Engine

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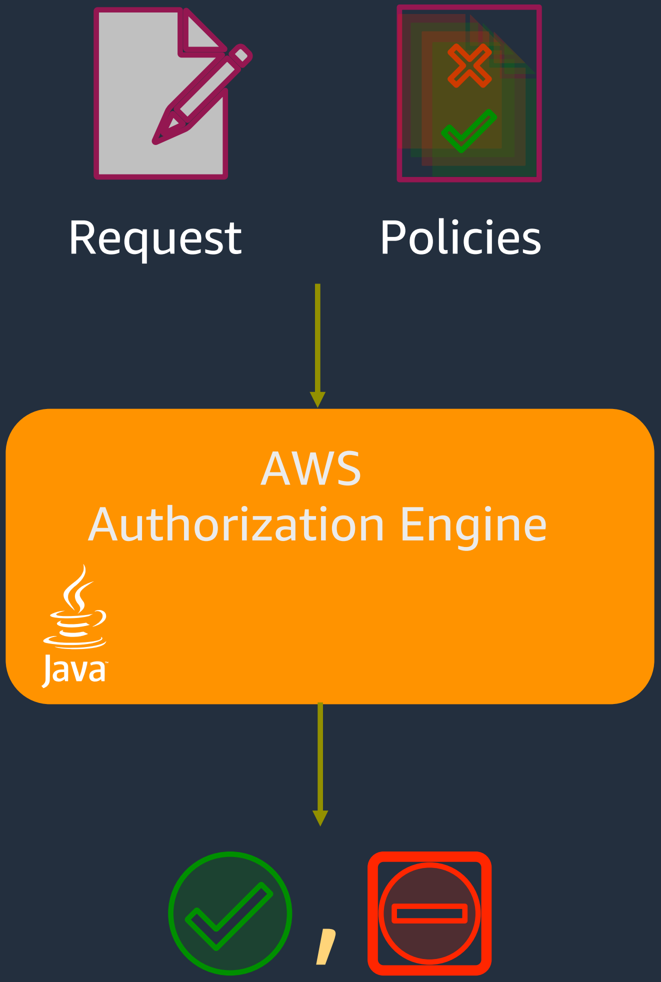
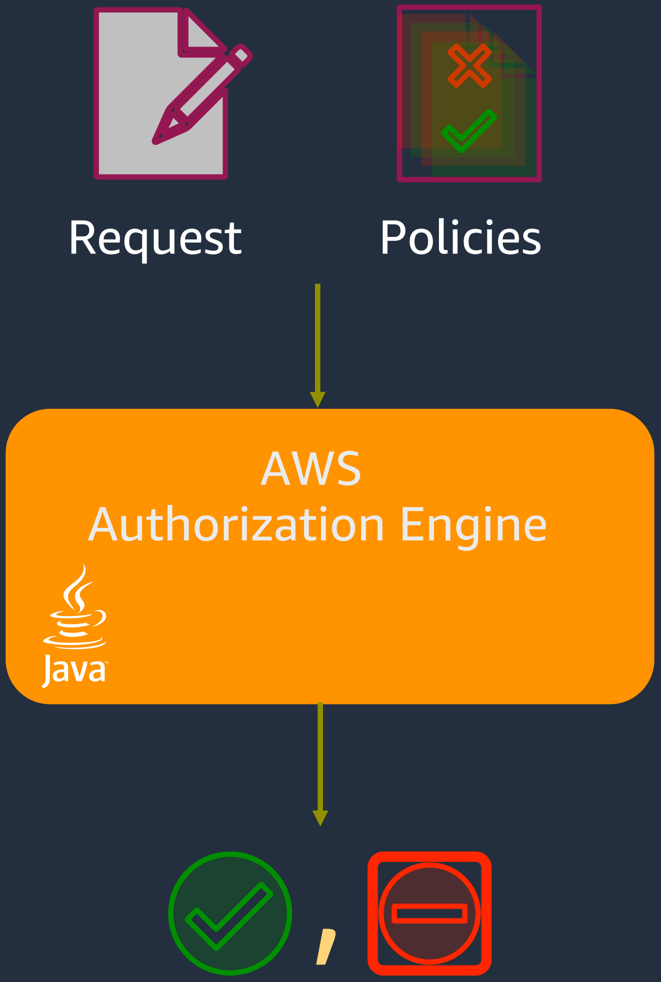


Is principal P allowed to perform action A with resource R under conditions C?

Backward Compatibility of AWS Authorization Engine



Is principal P allowed to perform action A with resource R under conditions C?

AWS authorizes **~34 trillion** API calls / day

Backward Compatibility of AWS Authorization Engine

- Changes to the Authorization Engine
  - Performance updates
  - Feature updates
  - Algorithmic updates

Backward Compatibility of AWS Authorization Engine

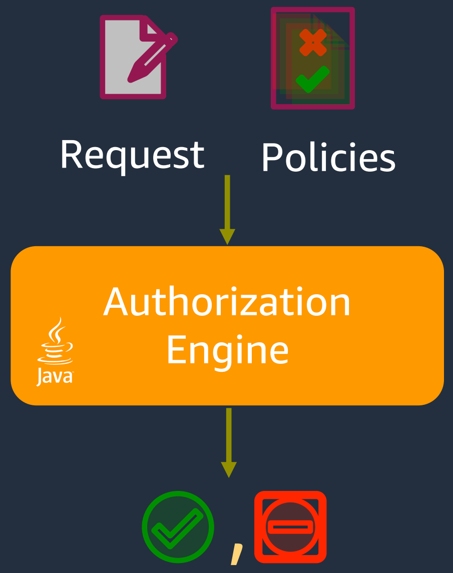
- Changes to the Authorization Engine
  - Performance updates
  - Feature updates
  - Algorithmic updates

Engineers seek answers to:

- How does this change affect the existing implementation?
- Is it backward compatible?
- Does this change affect the existing authorization strategy?

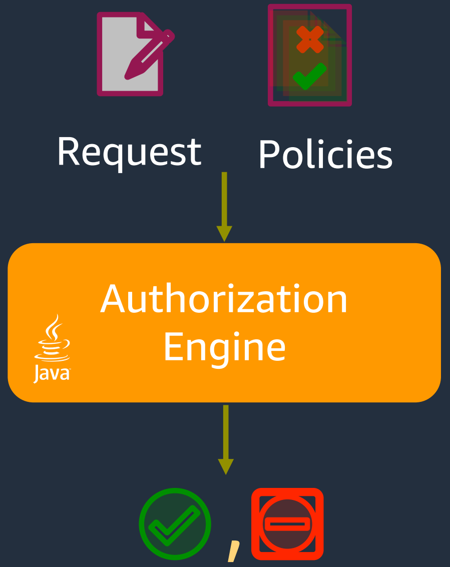
Yucca — Verified AWS Authorization Engine

- The Yucca project — started in the spring 2020
- Goals
  - Have a high level specifications of the Authorization Engine
  - Prove authorization properties
  - Prove backward compatibility going forward



Yucca — Verified AWS Authorization Engine

- The Yucca project — started in the spring 2020
- Goals
  - Have a high level specifications of the Authorization Engine
  - Prove authorization properties
  - Prove backward compatibility going forward
    - Apply typeCart to semi-automate the process



Can You use typeCart?

- Absolutely yes!

available on GitHub:
`awslabs/typecart`

- Want to analyze the effect of introducing changes to your Dafny development?
  - typeCart is here

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- Questions!