LASIGE reliable software systems

LayeredTypes

Combining Dependent and Independent Type Systems

TYPES'23, Valencia

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This work was supported by *Fundação para a Ciência e Tecnologia* (FCT) in the LASIGE Research Unit under the ref. UIDB/00408/2020 and UIDP/00408/2020, by the CMU--Portugal project CAMELOT (LISBOA-01-0247-FEDER-045915), and the RAP project under the reference (EXPL/CCI-COM/1306/2021)

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FOREWORD

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  - Implementation

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MOTIVATION

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

- Original Idea comes from challenges in Liquid Types:
  - Composability
  - Reusability
  - Error-Detection

Untyped

```
x = 100
-- Do something with x
x = -10
```

Typed

```
x :: Int
x = 100
-- Do something with x
x = -10
```

Liquid Typed

```
{-@ x :: { v:Int | v > 0} @-}
x :: Int
x = 100
-- Do something with x
x = -10 -- ERROR with liquid types
```

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LayeredTypes – Motivation

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

Before

```
{-@ type OrderedList = { v:[Int] | len(v) > 0
                         && all(i,j | i<j ⇒ v[i]<v[j]) } @-}
{-@ type PositiveList = { v:[Int] | len(v) > 0
                         && all( i | v[i] > 0 ) } @-}

{-@ foo :: OrderedList → Int @-}
foo :: [Int] → Int

{-@ x :: PositiveList @-}
x :: [Int]

foo(x) = ... -- Perform some complicated operation
```

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{-@ foo :: OrderedList → Int @-}
foo :: [Int] → Int

{-@ x :: PositiveList @-}
x :: [Int]

foo(x) = ...  -- Perform some complicated operation
```

```
Error: type of 'x' is not compatible with liquid type:
{ v:[Int] | len(v) > 0 && all(i,j | i<j ⇒ v[i] < v[j]) }
```

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LayeredTypes – Motivation

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

After

```
{-@ layer NonEmpty = { v:[Int] | len(v) > 0 } @-}
{-@ layer Ordered =  { v:[Int] | all( i,j | i<j ⇒
                                  v[i] < v[j] ) } @-}
{-@ layer Positive = { v:[Int] | all( i | v[i] > 0 ) } @-}

{-@ foo :: { NonEmpty && Ordered } → Int @-}
foo :: [Int] → Int

{-@ x :: { NonEmpty && Positive } @-}
x :: [Int]

foo(x) = ...  -- Perform some complicated operation
```

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LayeredTypes – Motivation

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LASIGE reliable software systems

After

```
{-@ layer NonEmpty = { v:[Int] | len(v) > 0 } @-}
{-@ layer Ordered =  { v:[Int] | all( i,j | i<j ⇒
                                  v[i] < v[j] ) } @-}
{-@ layer Positive = { v:[Int] | all( i | v[i] > 0 ) } @-}

{-@ foo :: { NonEmpty && Ordered } → Int @-}
foo :: [Int] → Int

{-@ x :: { NonEmpty && Positive } @-}
x :: [Int]

foo(x) = ...  -- Perform some complicated operation
```

```
Error: type of ‘x’ is not compatible with layer Ordered
```

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LAYEREDTYPES – MOTIVATION

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

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LayeredTypes – Motivation

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

- Applying this to Liquid Types is nice

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LayeredTypes – Motivation

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

- Applying this to Liquid Types is nice

- But can't we go bigger?
  - Similar problems when combining type systems
  - No unified tooling

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LayeredTypes – Motivation

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

- Applying this to Liquid Types is nice
- But can't we go bigger?
  - Similar problems when combining type systems
  - No unified tooling
- Can we build something "good"?

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LAYEREDTYPES – VISION

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

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LayeredTypes – Vision

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

- Incremental Verification
  - Layers build on top of each other
  - Can be verified individually

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LayeredTypes – Vision

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

- Incremental Verification
  - Layers build on top of each other
  - Can be verified individually
- Separation of Concerns
  - Each Layer is independent
  - Easier to develop, verify and test
  - Error-Detection might be easier

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LayeredTypes – Vision

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- Incremental Verification
  - Layers build on top of each other
  - Can be verified individually
- Separation of Concerns
  - Each Layer is independent
  - Easier to develop, verify and test
  - Error-Detection might be easier
- Modularity
  - Existing Layers can be reused
  - Layers can be composed arbitrarily

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LayeredTypes – Architecture

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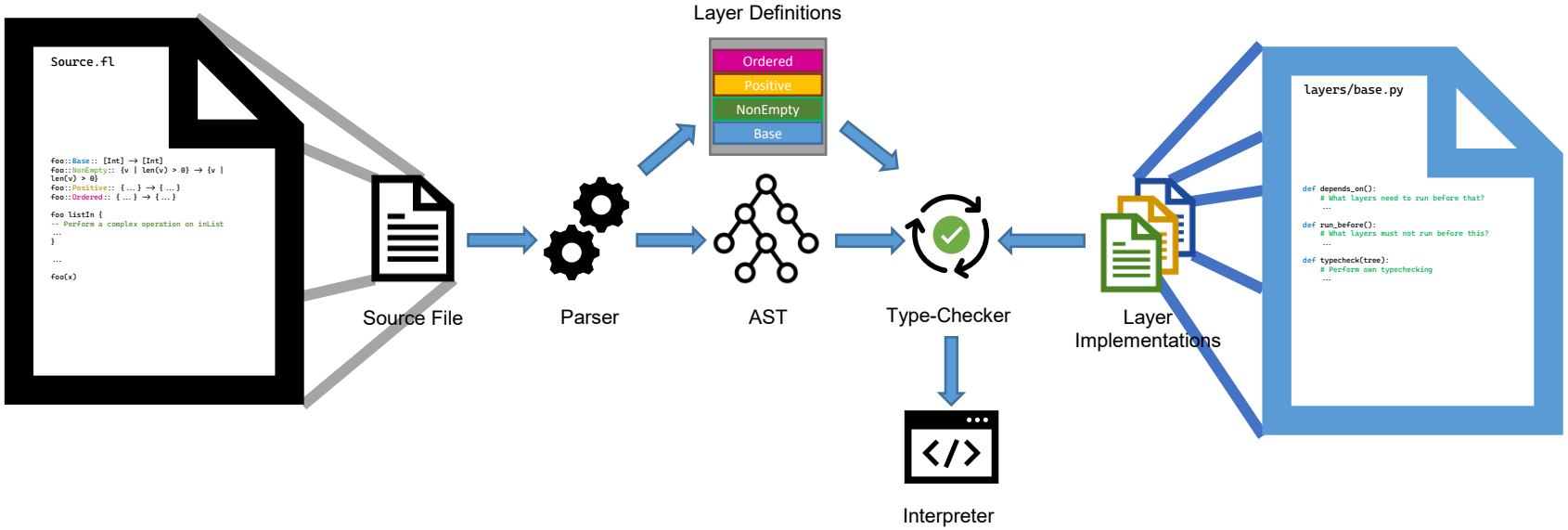

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LayeredTypes – Source Code

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factorial.fl

```
fac x {
    let cond := (x == 0) in {
            if cond then {
                    1
            } else {
                    x * fac (x - 1)
            }
    }
}

x := fac(5)
print(x)

x
```

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LAYEREDTYPES – LAYERS

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

layers.fl

```
x :: LayerA :: ...
x :: LayerB :: ...
x :: LayerC :: ...
x :: LayerD :: ...

x := 42
x
```

layer.py

```
def depends_on():
    # What layers need to run before that?
    ...

def run_before():
    # What layers must not run before this?
    ...

def typecheck(tree):
    # Perform own typechecking
    ...
```

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LayerA.py

```
def depends_on():
    return {}
```

LayerB.py

```
def depends_on():
    return {"LayerA"}
```

LayerC.py

```
def depends_on():
    return {"LayerA"}
```

LayerD.py

```
def depends_on():
    return {"LayerB", "LayerC"}
```

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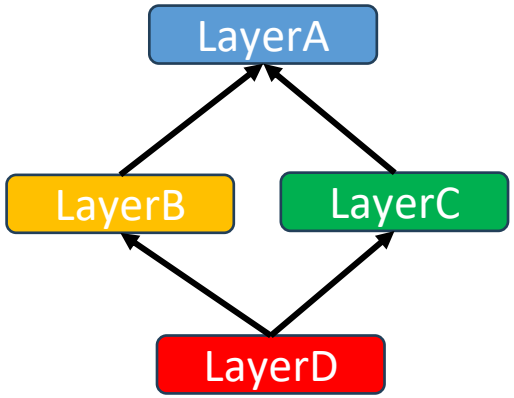

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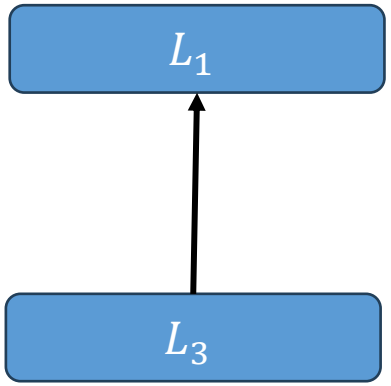

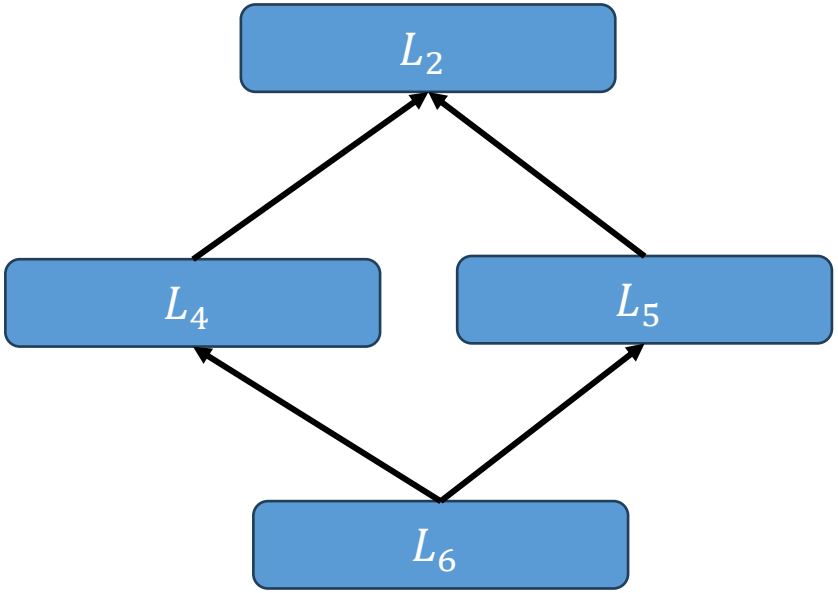

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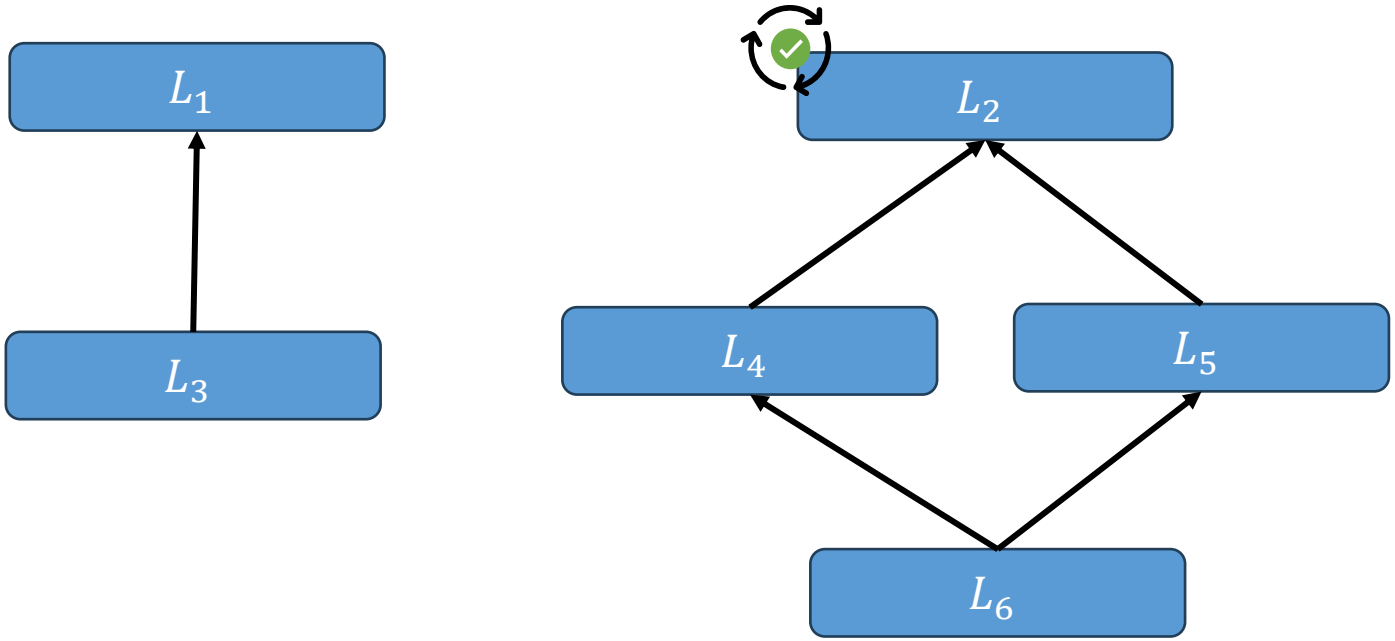

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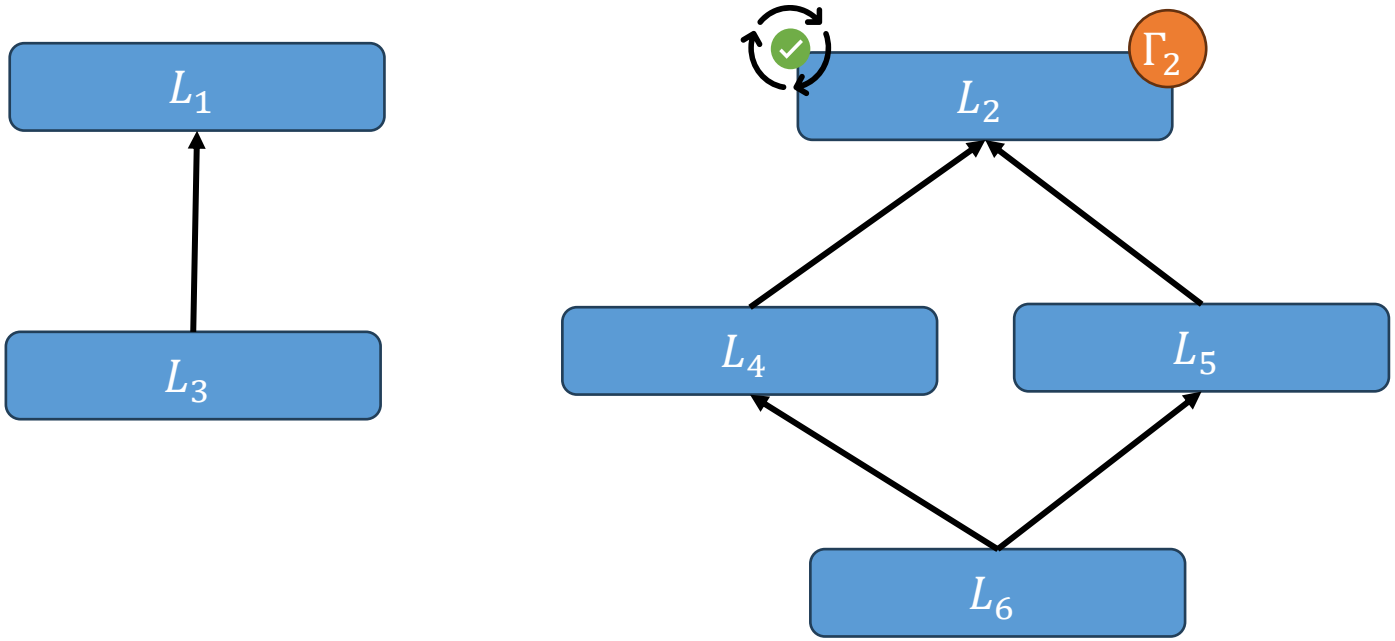

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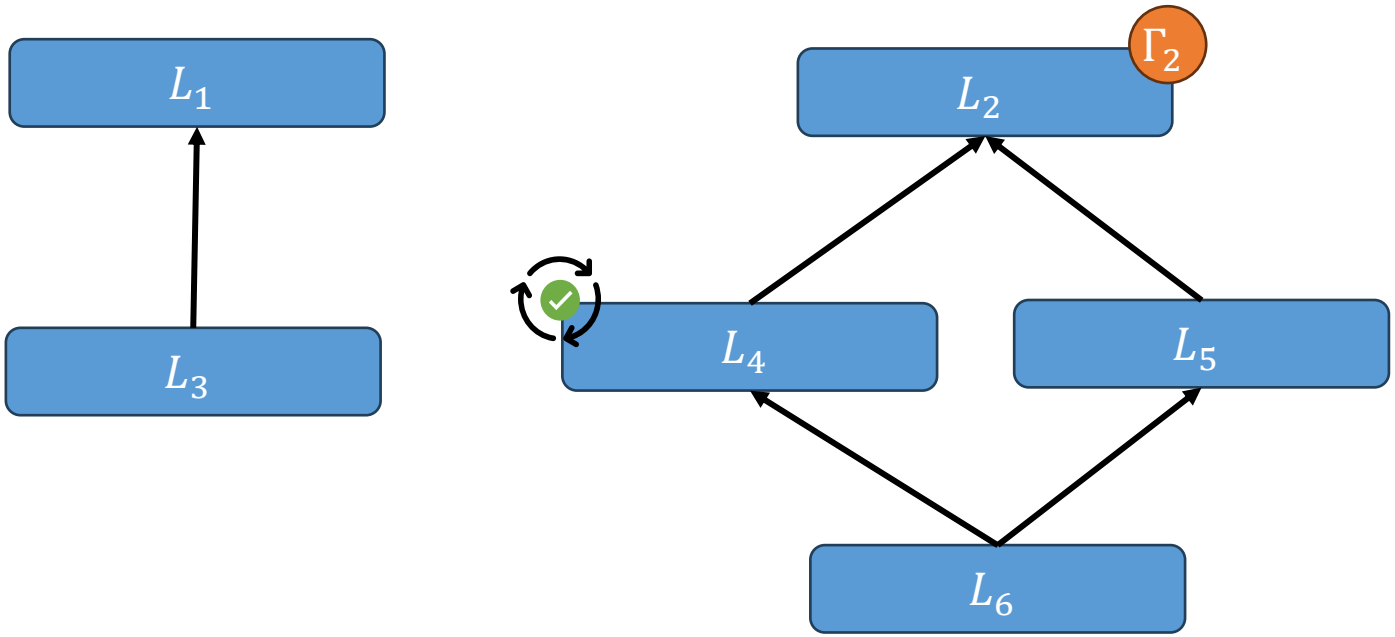

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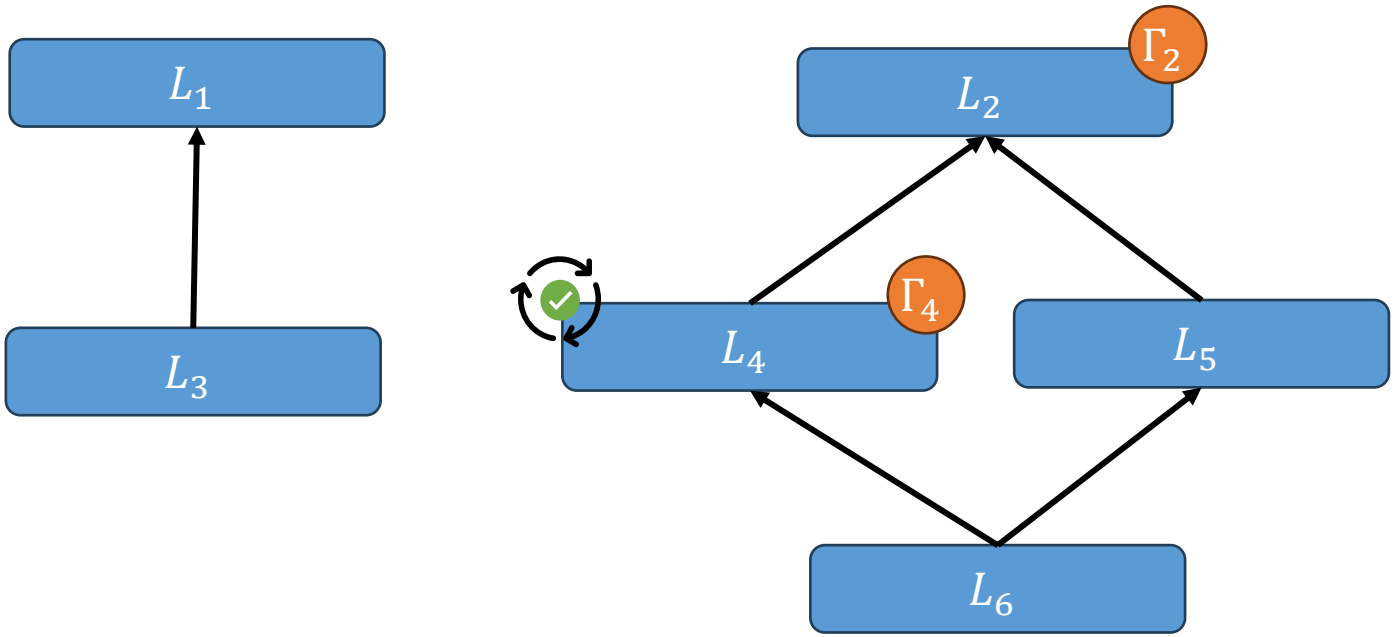
LayeredTypes – Layers

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems



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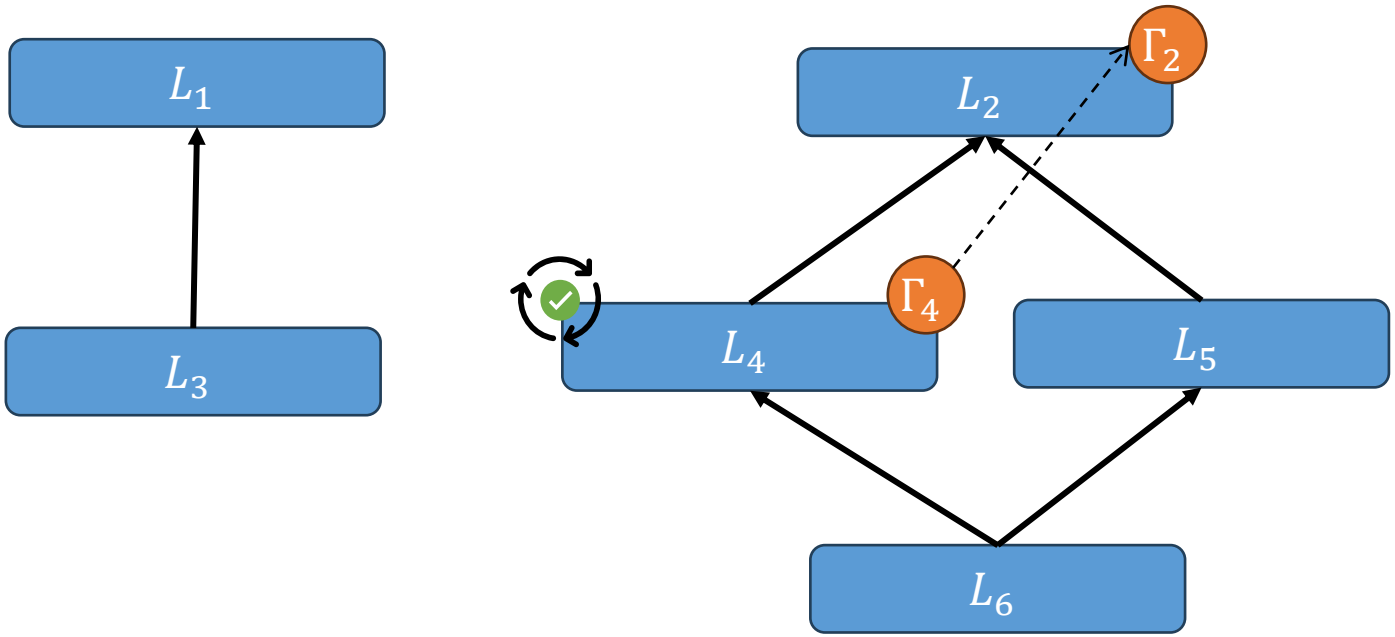

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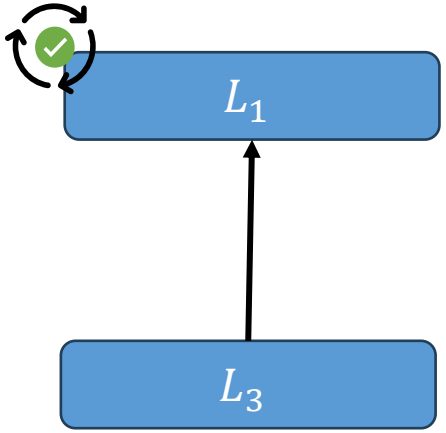

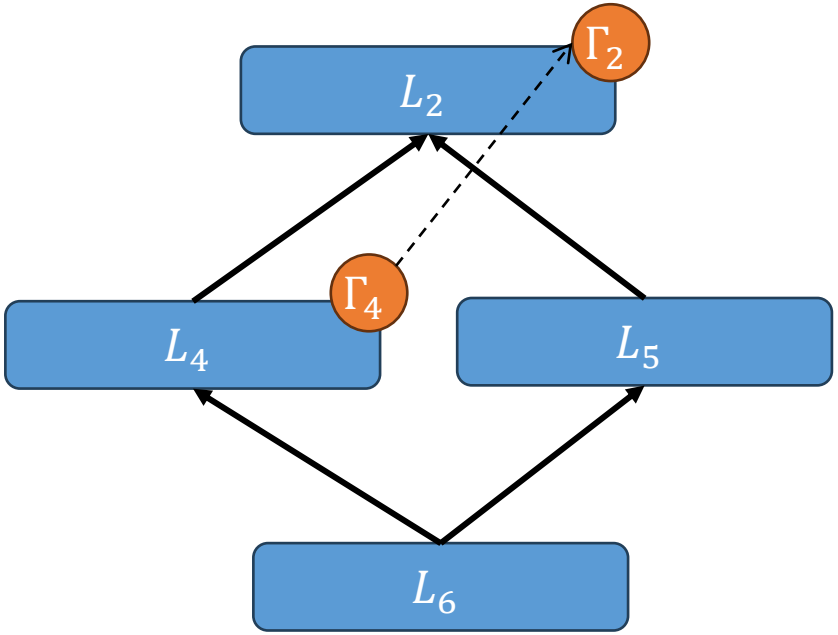

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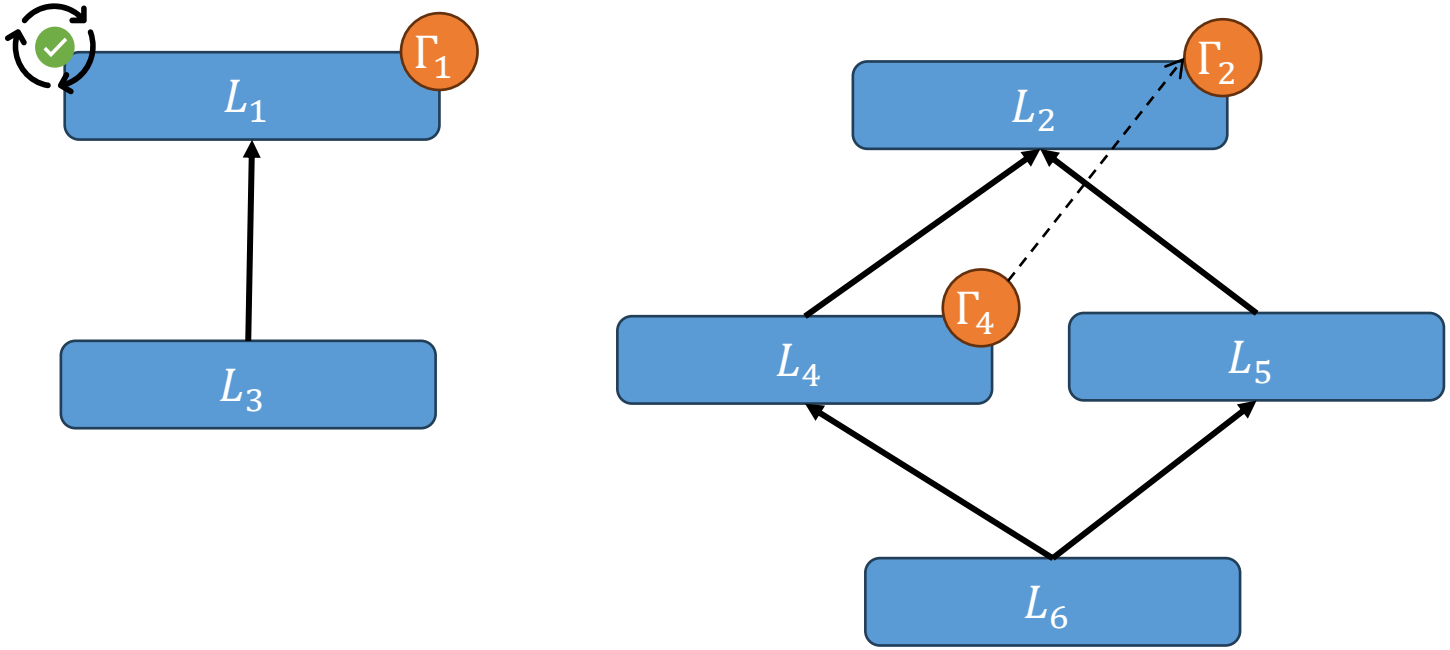

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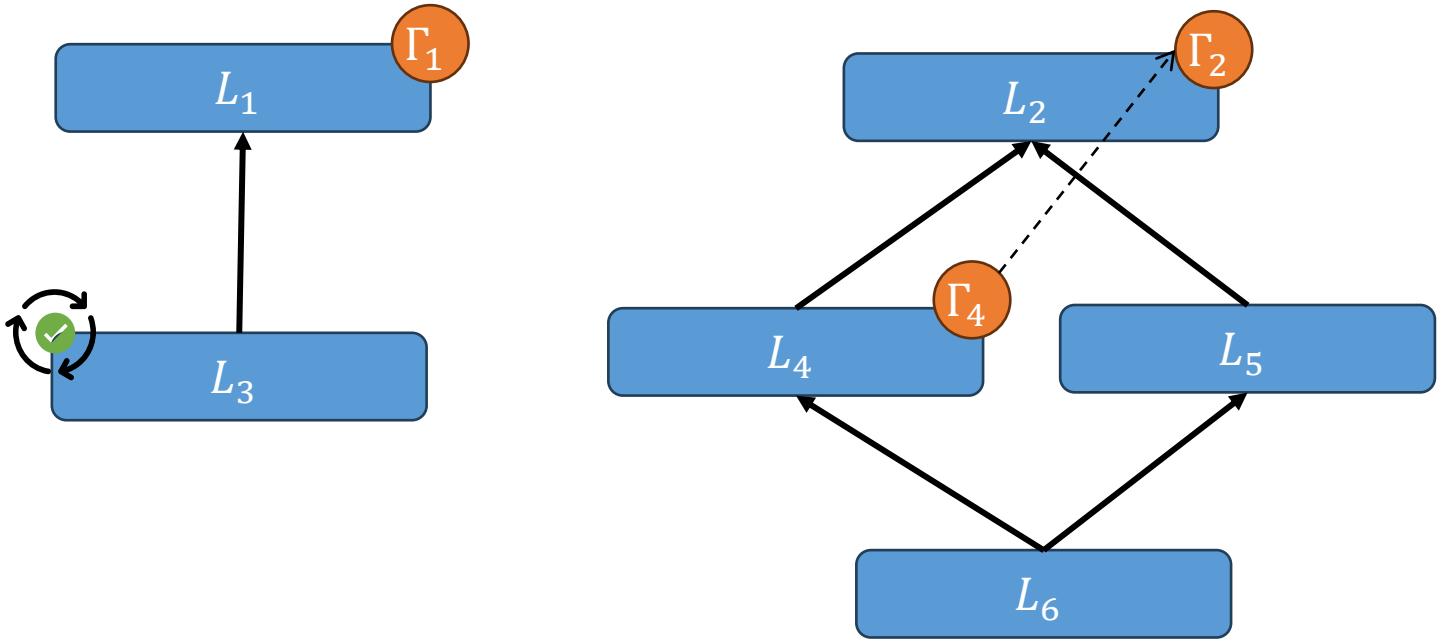

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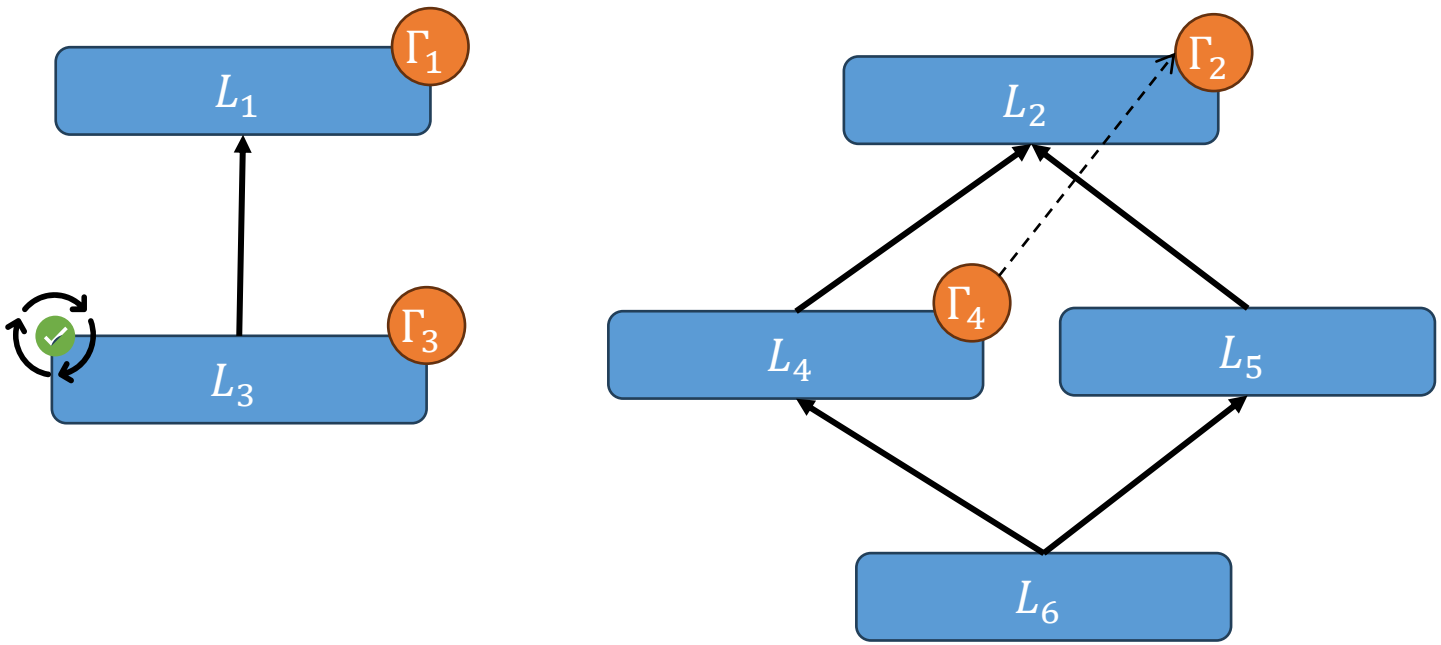

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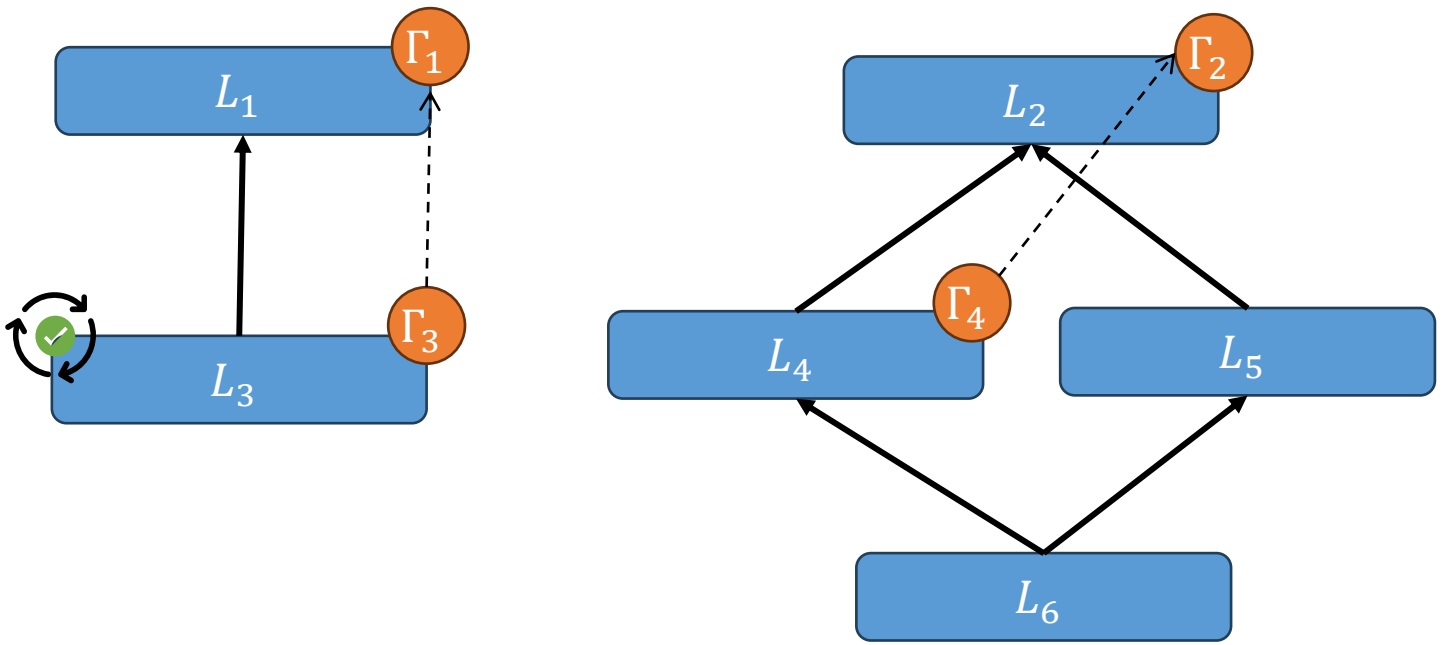

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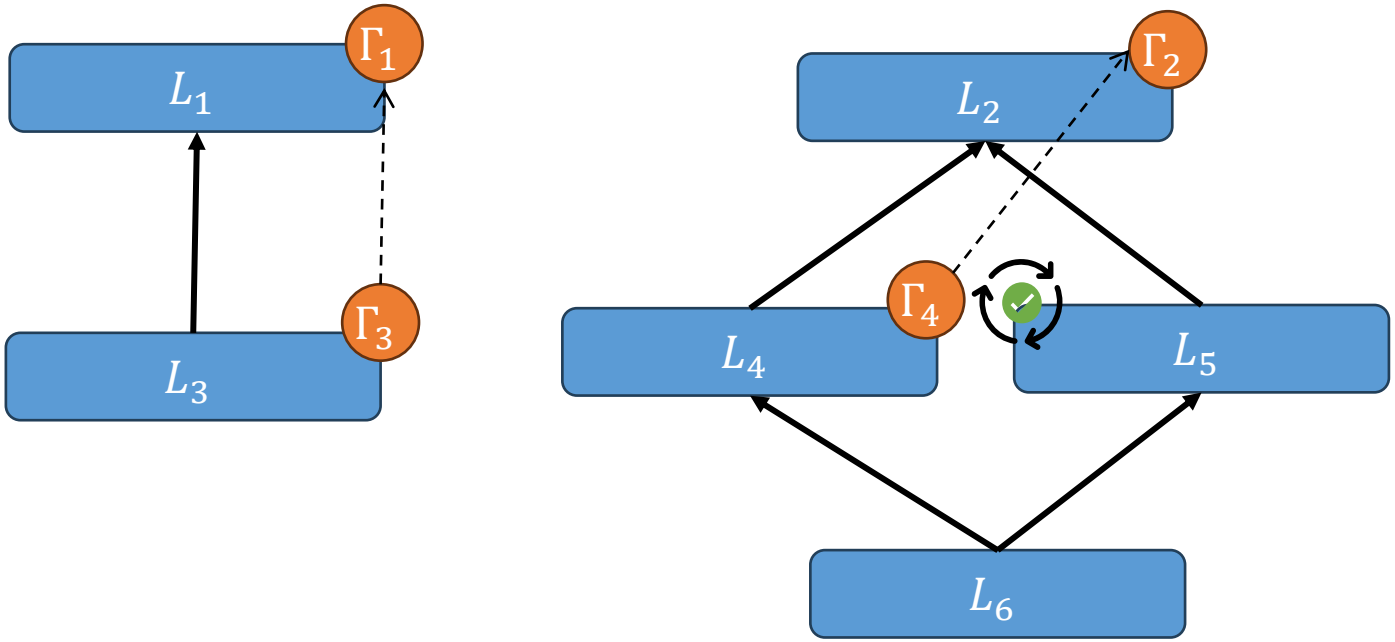

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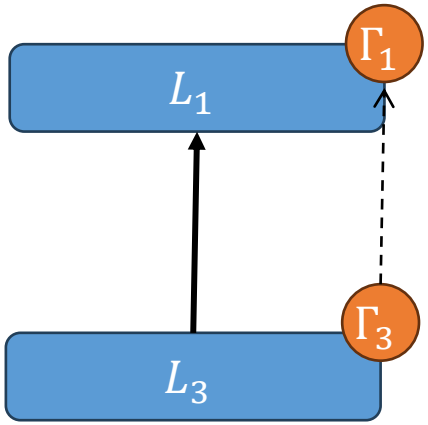

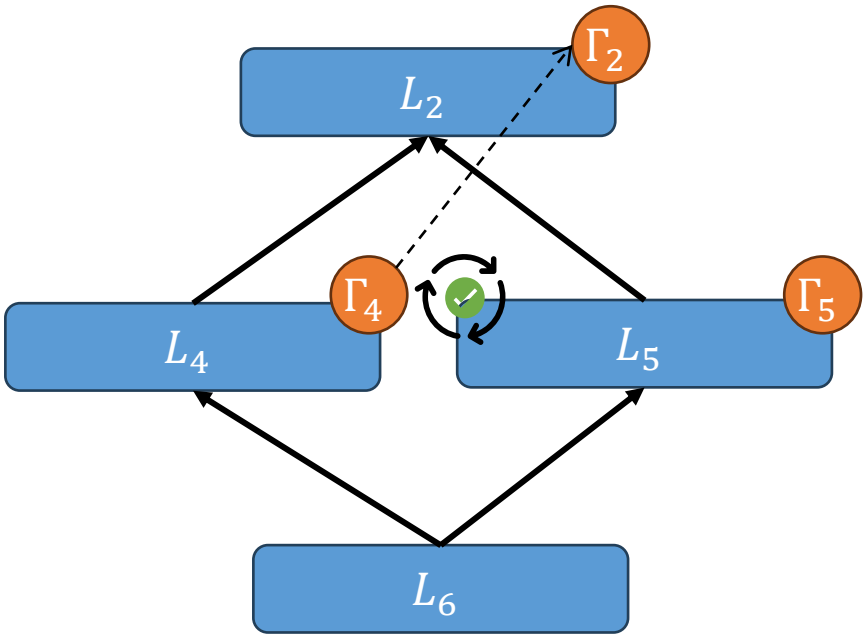

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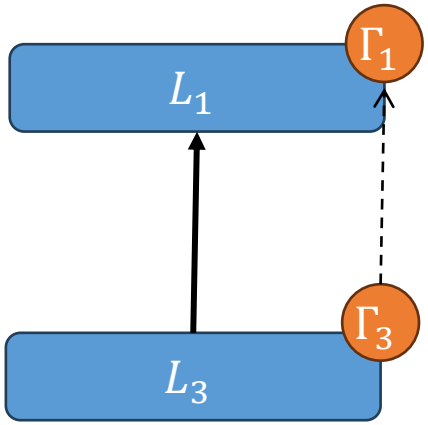

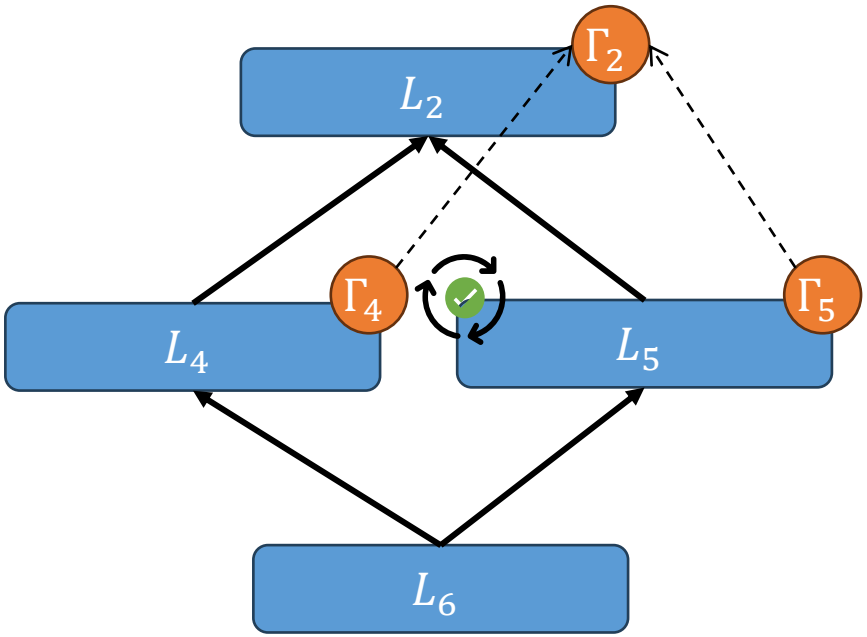

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LAYEREDTYPES – LAYERS

Lukas Abelt, Alcides Fonseca

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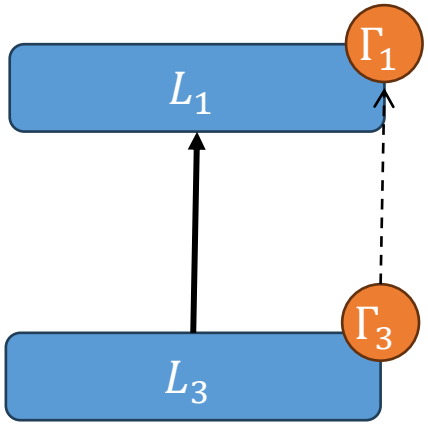

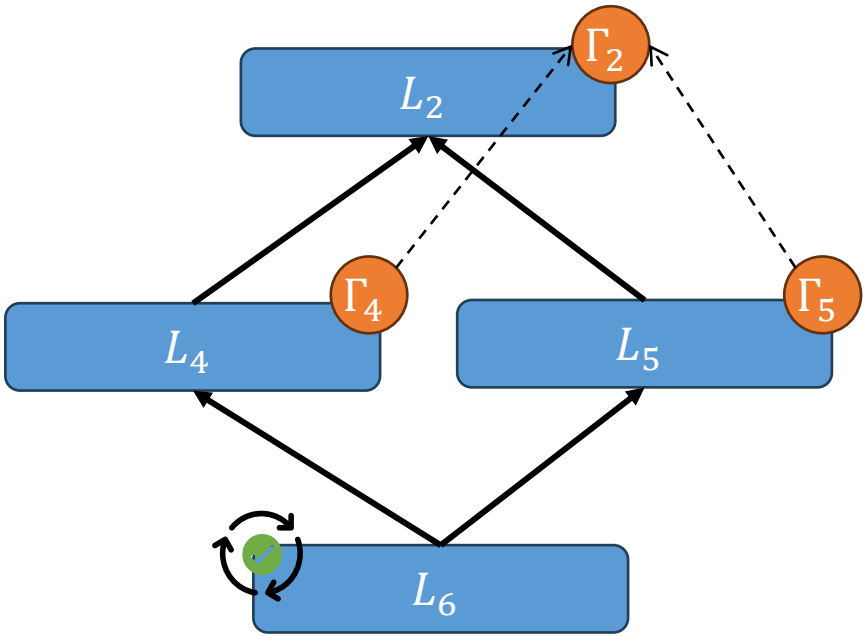

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LayeredTypes – Layers

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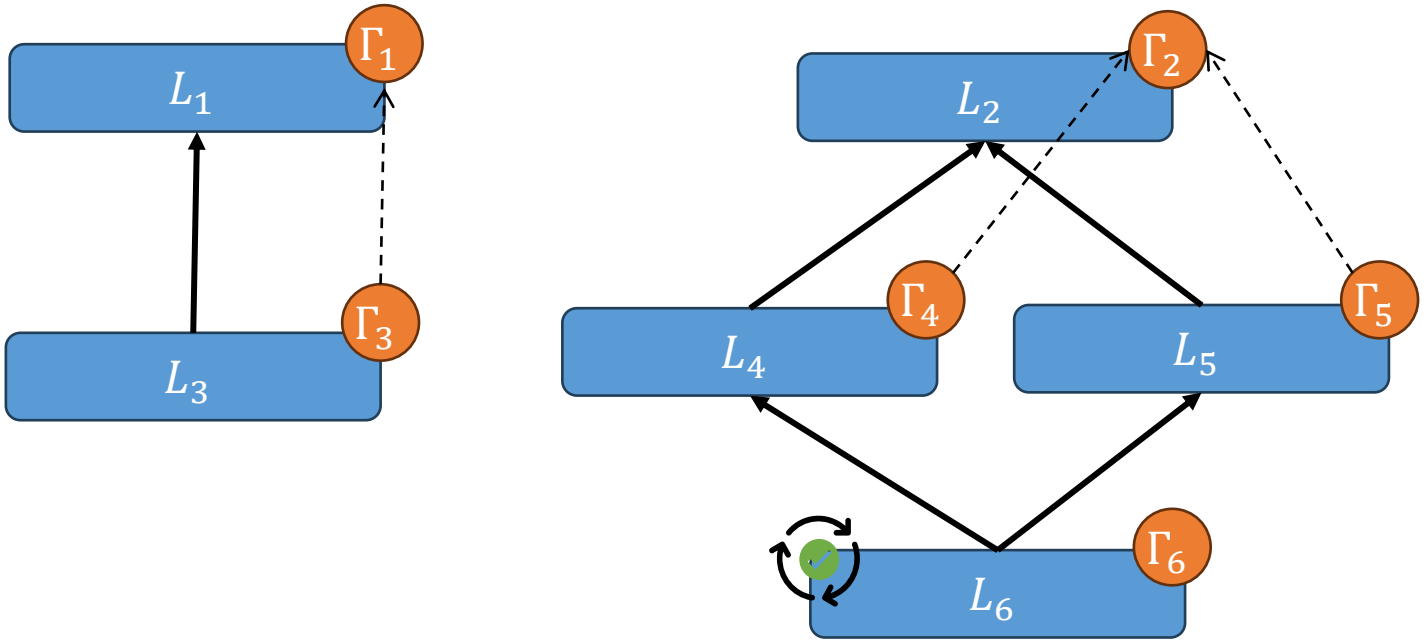

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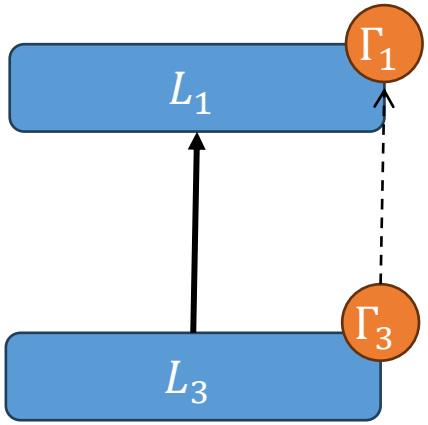

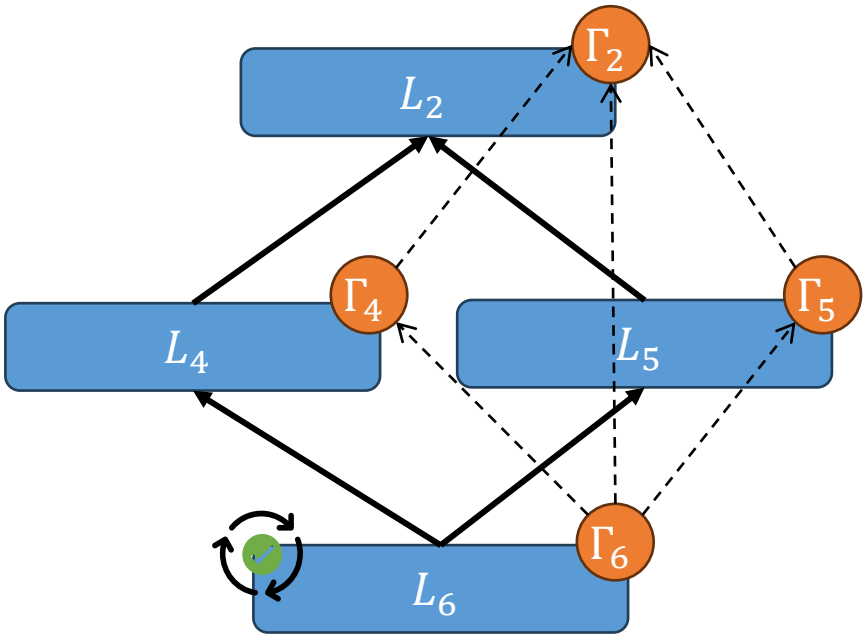

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LayeredTypes - Results

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

- What did we achieve:
  - Prototypical implementation
    - https://github.com/LuAbelt/LayeredTypes
  - Example Layers
    - “Normal” Typechecking
    - States
    - Layered Liquid Types
  - How far did we get with our vision?

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LayeredTypes – Results

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

- Incrementality ☑
  - Layers are verified independently
- Modularity ☑
  - Layers may be combined arbitrarily
  - Some restrictions may apply
- Separation of Concerns ⚠
  - Generally yes, but…

```
lukas@DESKTOP-H22A5SC
└/mnt/c/Projects/LayeredTypes/tests
$ python3 ../main.py -f ./test_code/layers/complex_layers.fl -l ./layer_imp
lementations/ -i ./implementations.py -t
Not all layers could be verified.
The following cycle in the layer dependency graph was detected:
        cycleB
        cycleA
The following layers were processed:
        A: SUCCESS
        B: SUCCESS
        C: SUCCESS
        D: SUCCESS
        cycleA: CYCLE
        cycleB: CYCLE
        failLayerA: FAILURE
        blockedLayerB: BLOCKED
        blockedLayerC: BLOCKED
        dependOnCycleA: CYCLE_BLOCKED


The following layers failed during typechecking:
        failLayerA:
         Layer 'failLayerA' failed with error: Layer A failed
```

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LayeredTypes – Errors

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

dimensions.fl

```
create :: rows :: { r:Int | r>0 } → { c:Int | true } → {
                    d:DataSet | n_rows(d)==r }
create :: cols :: { r:Int | true } → { c:Int | c>0 } → {
                    d:DataSet | n_cols(d)==c }
create :: dims :: { r:Int | true } → { c:Int | true } → {
                    d:DataSet | true }

data :: dims :: { d:DataSet | n_cols(d) ≥ (n_rows(d)*10) }
data :: rows :: { drf:DataSet | true }
data :: cols :: { dcf:DataSet | true }

let data := create(5,10) in {
    data
}
```

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LayeredTypes – Errors

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

```
dimens
create
create
create
data
data
data
let da
    da
}
```

```
lukas@DESKTOP-H22A5SC
└/mnt/c/Projects/LayeredTypes/tests
$ python3 ../main.py -f dimensions.fl -i ./implementations.py -l ../layer_i
mplementations/ -t
Not all layers could be verified.
The following layers were processed:
        rows: SUCCESS
        cols: SUCCESS
        dims: FAILURE


The following layers failed during typechecking:
        dims:
         Layer 'dims' failed with error: 9:1: Error during assigning identi
fier 'data' in let statement:
{ d:DataSet | ((true && (n_rows(d) == create_r)) && (n_cols(d) == create_c)
) } is not a subtype of { d:DataSet | (n_cols(d) ≥ (n_rows(d) * 10)) }
In Context:
create_c : { v:Int | (((v == 10) && (v == 10)) && (v == 10)) }
create_r_1_1 : { v:Int | (v == 5) }
create_r_1 : { v:Int | (v == 5) }
create_r : { v:Int | (((v == 5) && (v == 5)) && (v == 5)) }
 (line 9)
```

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LayeredTypes – Future

Lukas Abelt, Alcides Fonseca

LASIGE reliable software systems

- LayeredTypes should be treated as a prototype/proof-of-concept
  - Not viable for real-world projects

- Future works includes formalization of the approach

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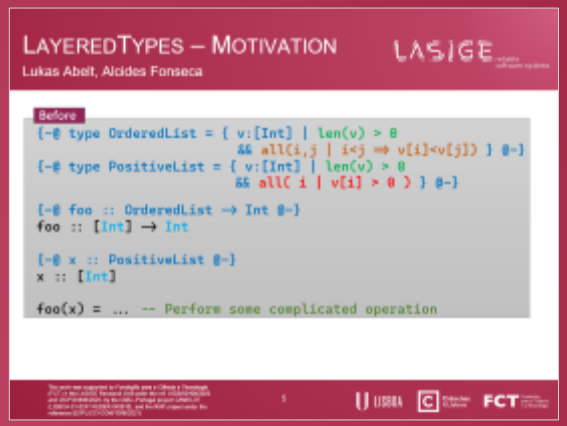
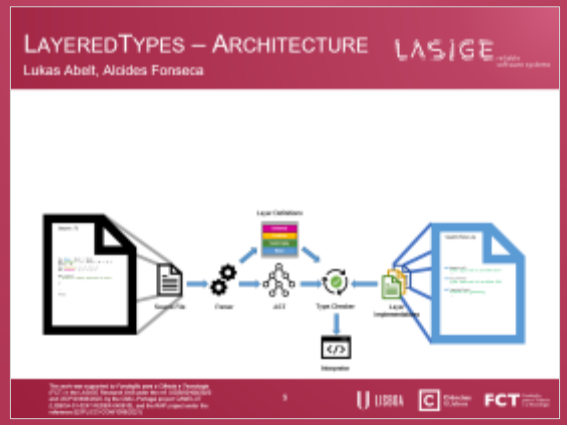
THANKS FOR YOUR ATTENTION!

LASIGE reliable software systems





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amfonsca@fc.ul.pt

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