Filesystems deserve verification too!

Gabriele Keller, Toby Murray, Sidney Amani,
Liam O'Connor, Zilin Chen, Leonid Ryzhyk
Gerwin Klein, Gernot Heiser

Australian Government
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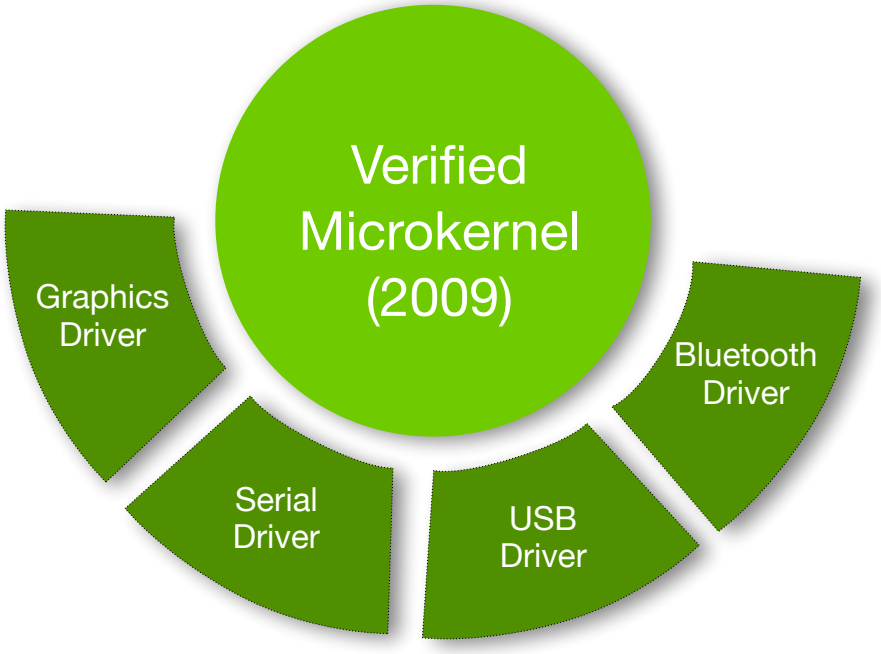
Griffith University
QUT
The University Of Queensland

Towards a trustworthy system

Towards a trustworthy system

Towards a trustworthy system

NICTA



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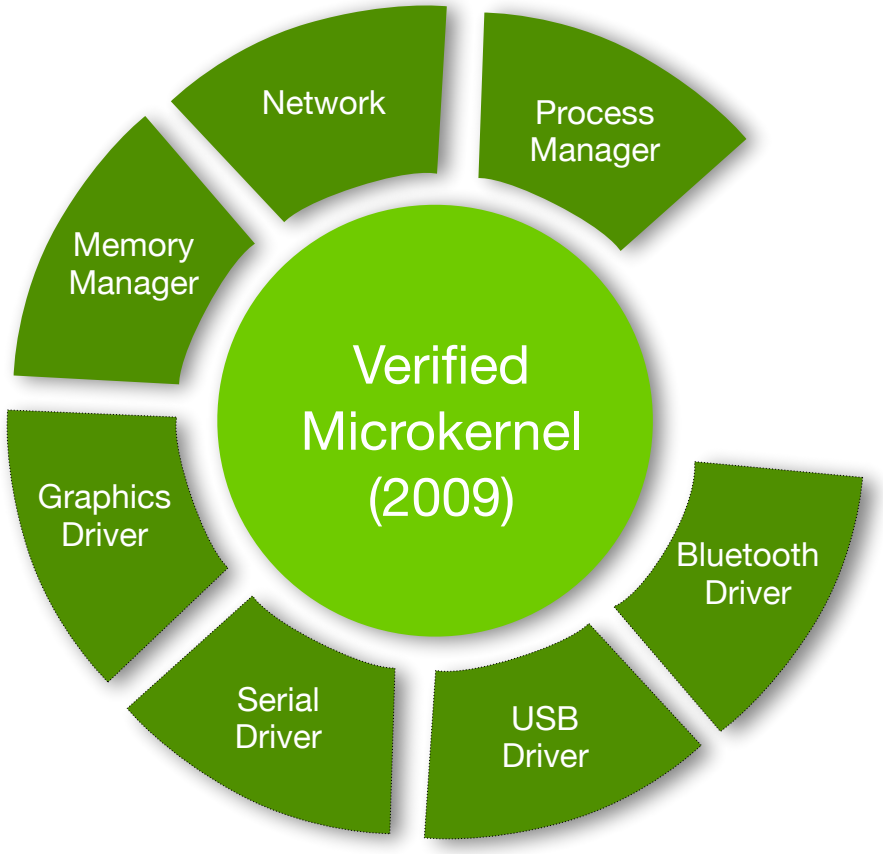

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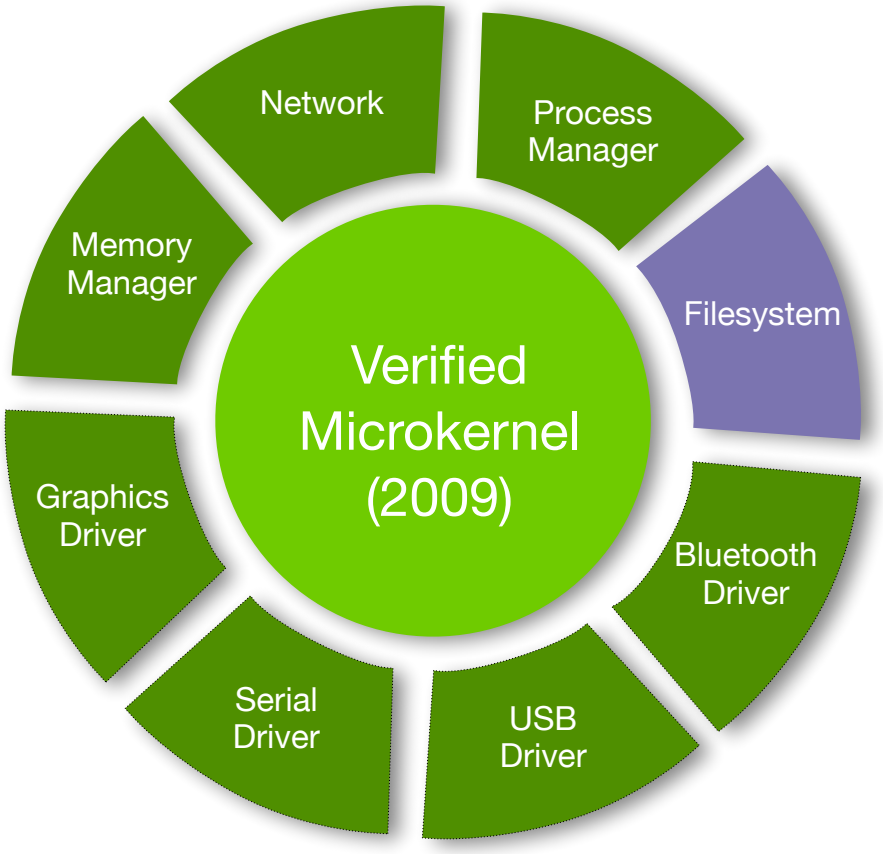

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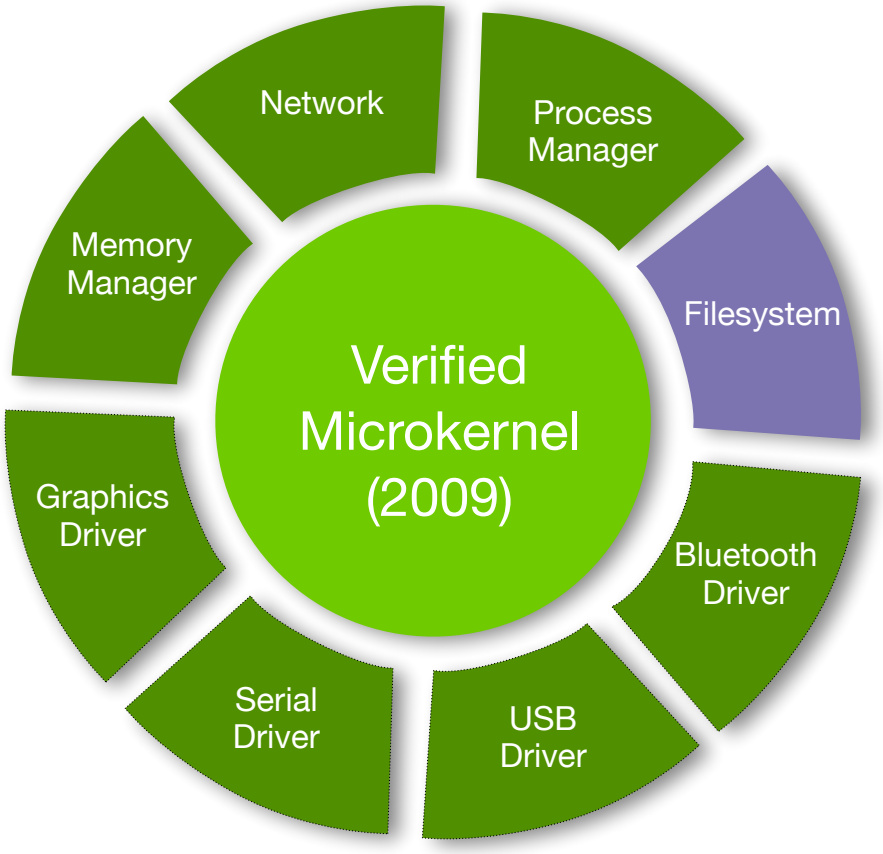

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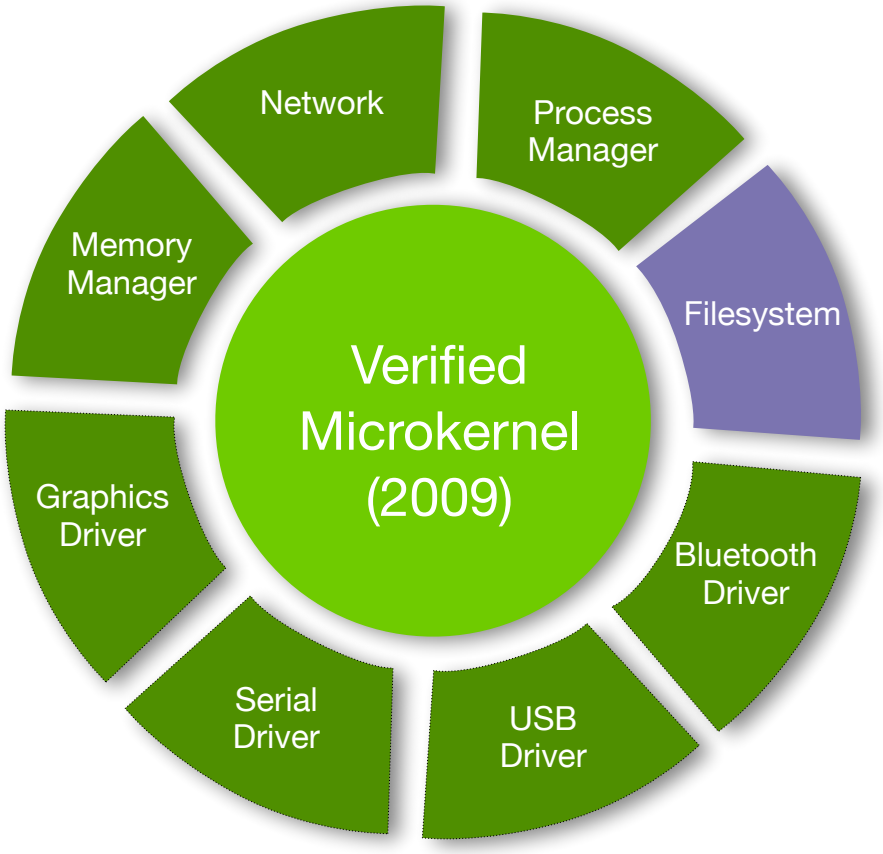

File System Bugs [Lu et al]

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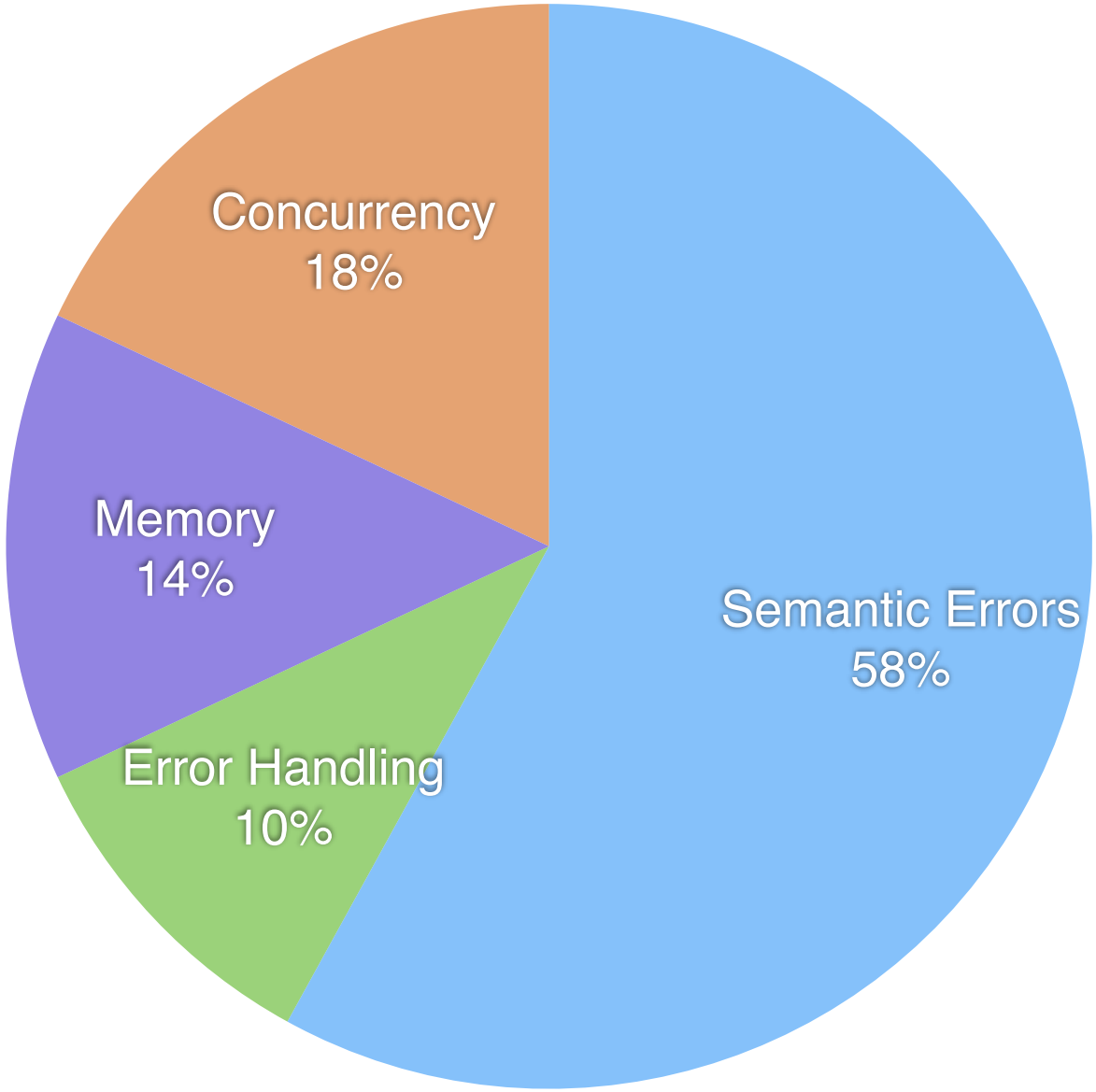

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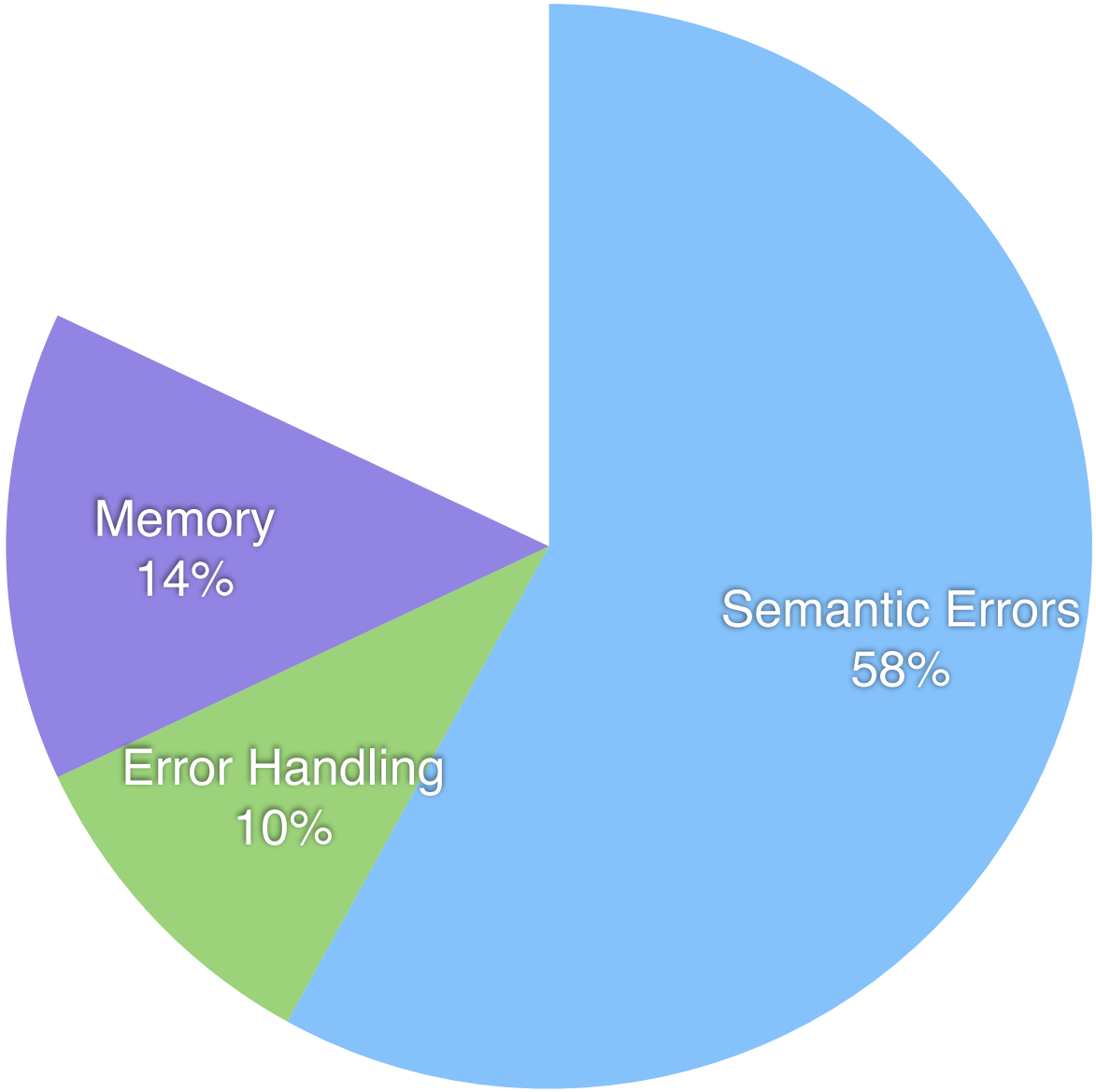

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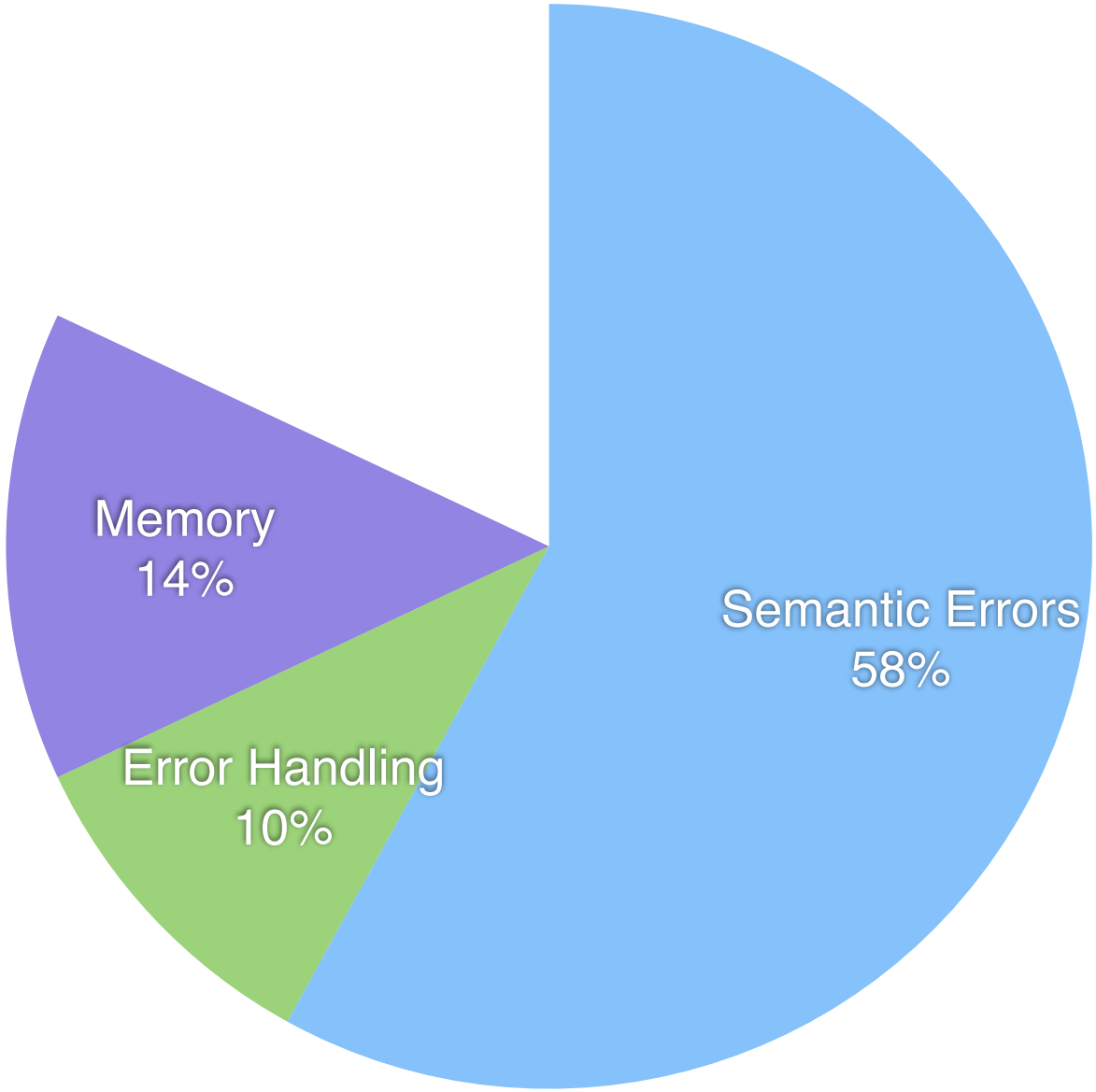

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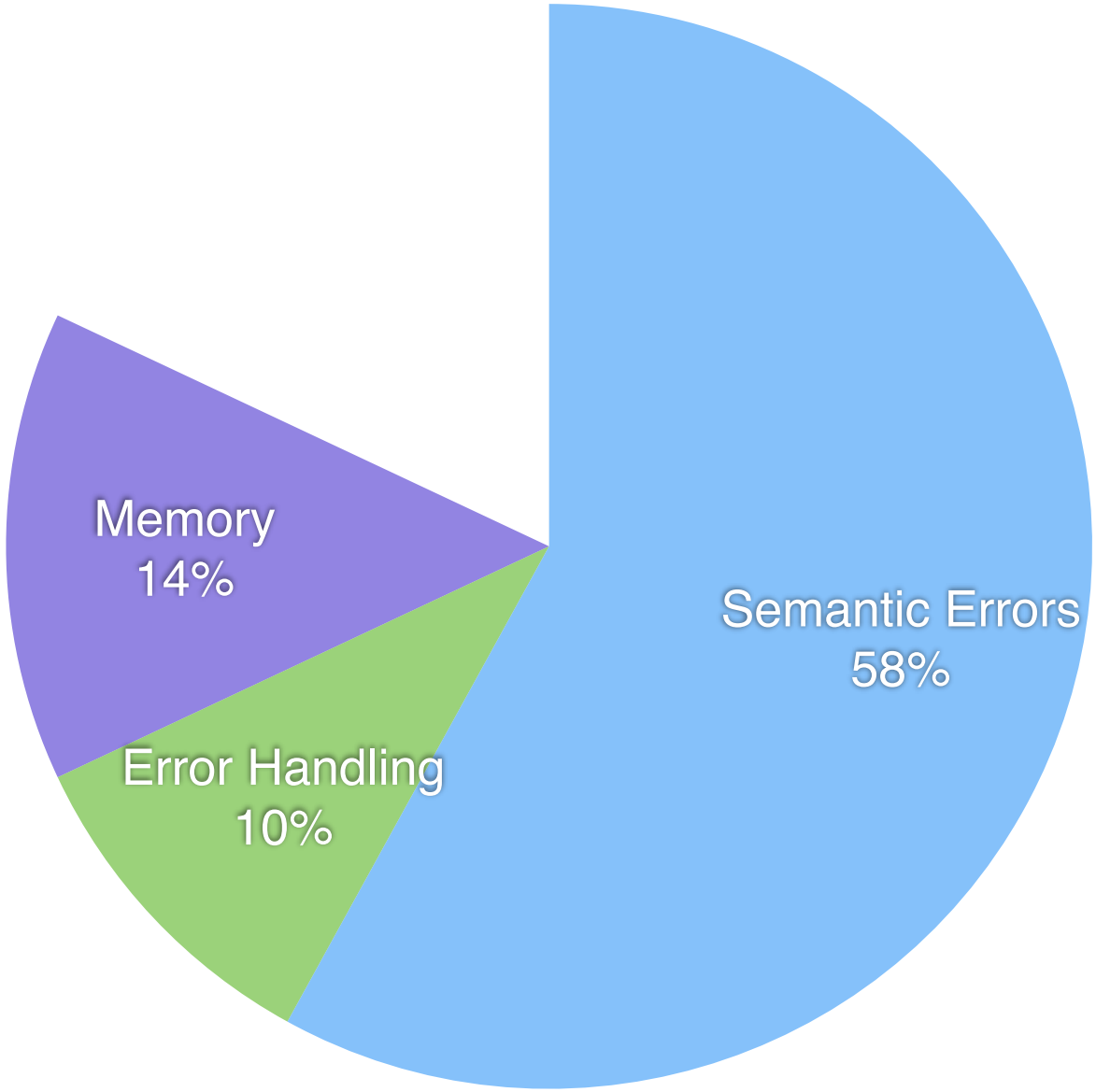

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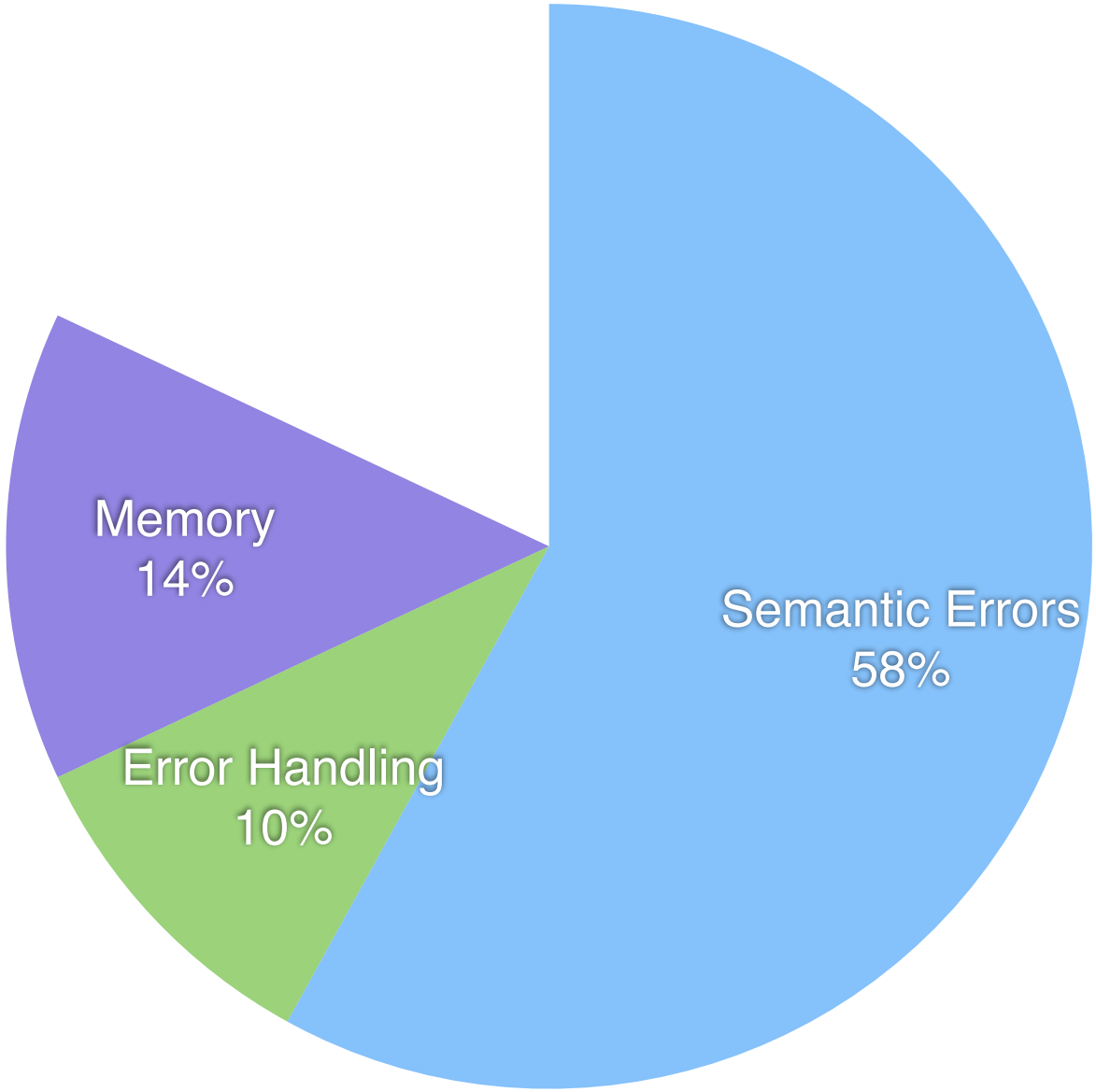


NICTA

Functional Specification

Filesystem Code

NICTA

Functional Specification

Refinement Proof

Filesystem Code

NICTA

Functional Specification

Refinement Proof

Low-level Specification

Refinement Proof

Filesystem Code

NICTA

Functional Specification

Refinement Proof

relatively easy to do manually
hard to automate

Low-level Specification

Refinement Proof

Filesystem Code

NICTA

Functional Specification

Refinement Proof

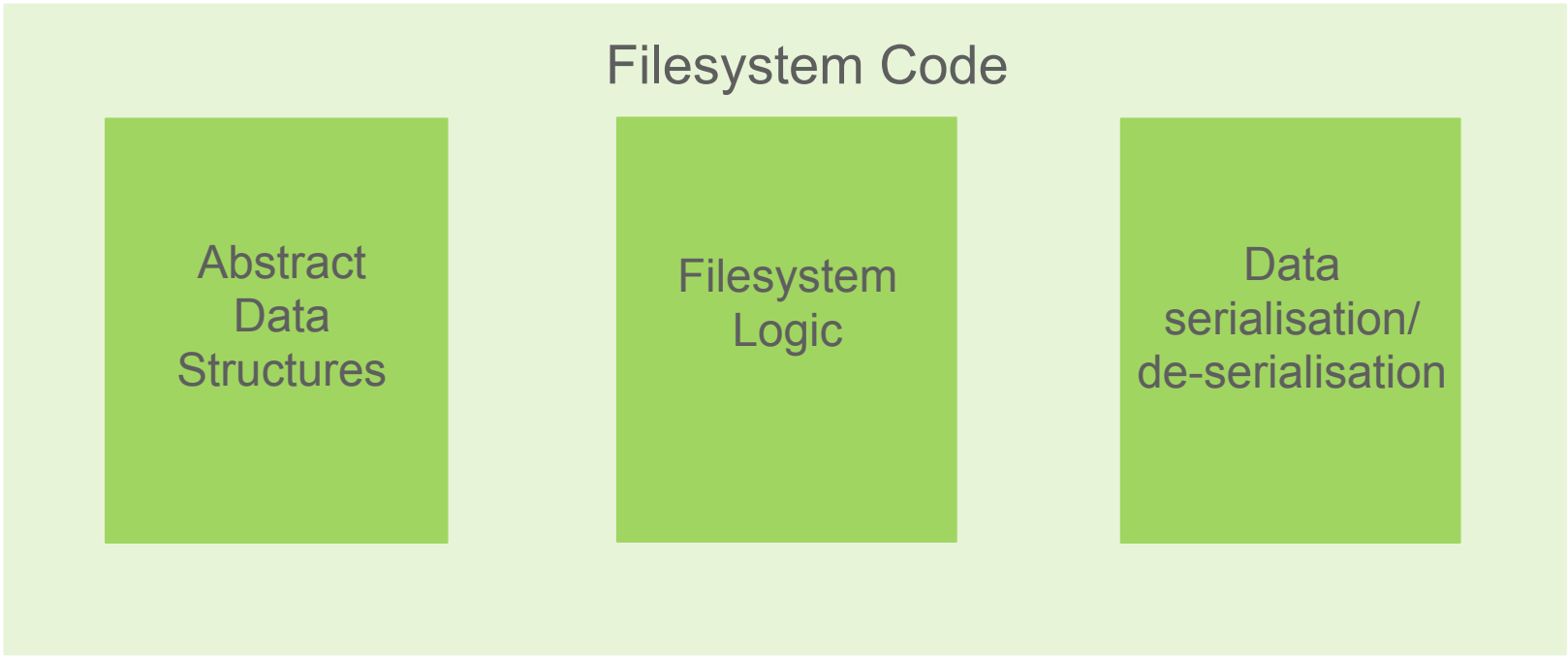
relatively easy to do manually
hard to automate

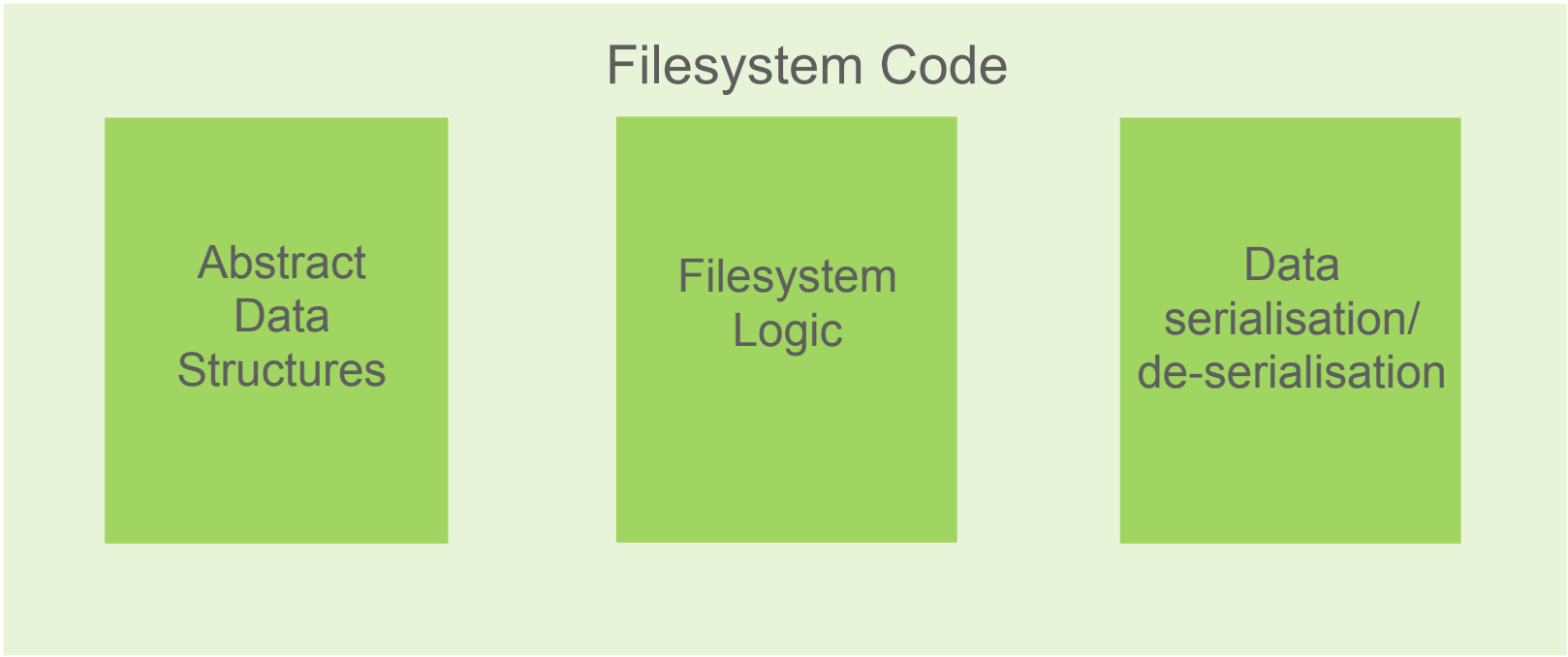
Low-level Specification

Refinement Proof

good candidate for automation

Filesystem Code





Isabelle Functional Specification

Filesystem

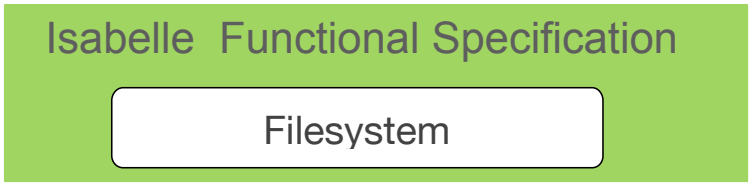
Isabelle Functional Specification

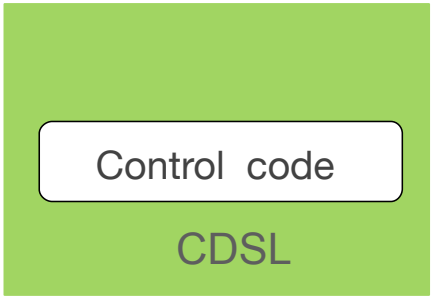
Filesystem

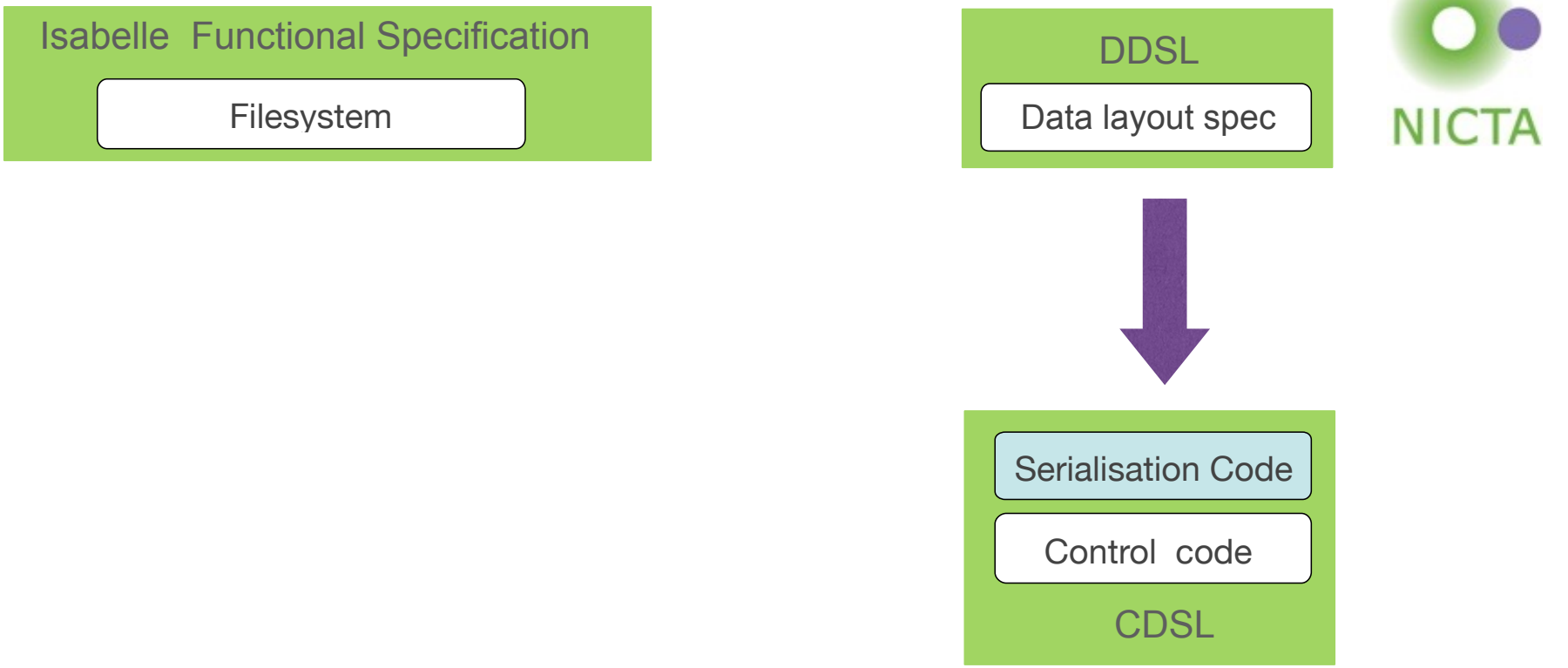
DDSL

Data layout spec

NICTA






Isabelle Functional Specification
Filesystem
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Data layout spec
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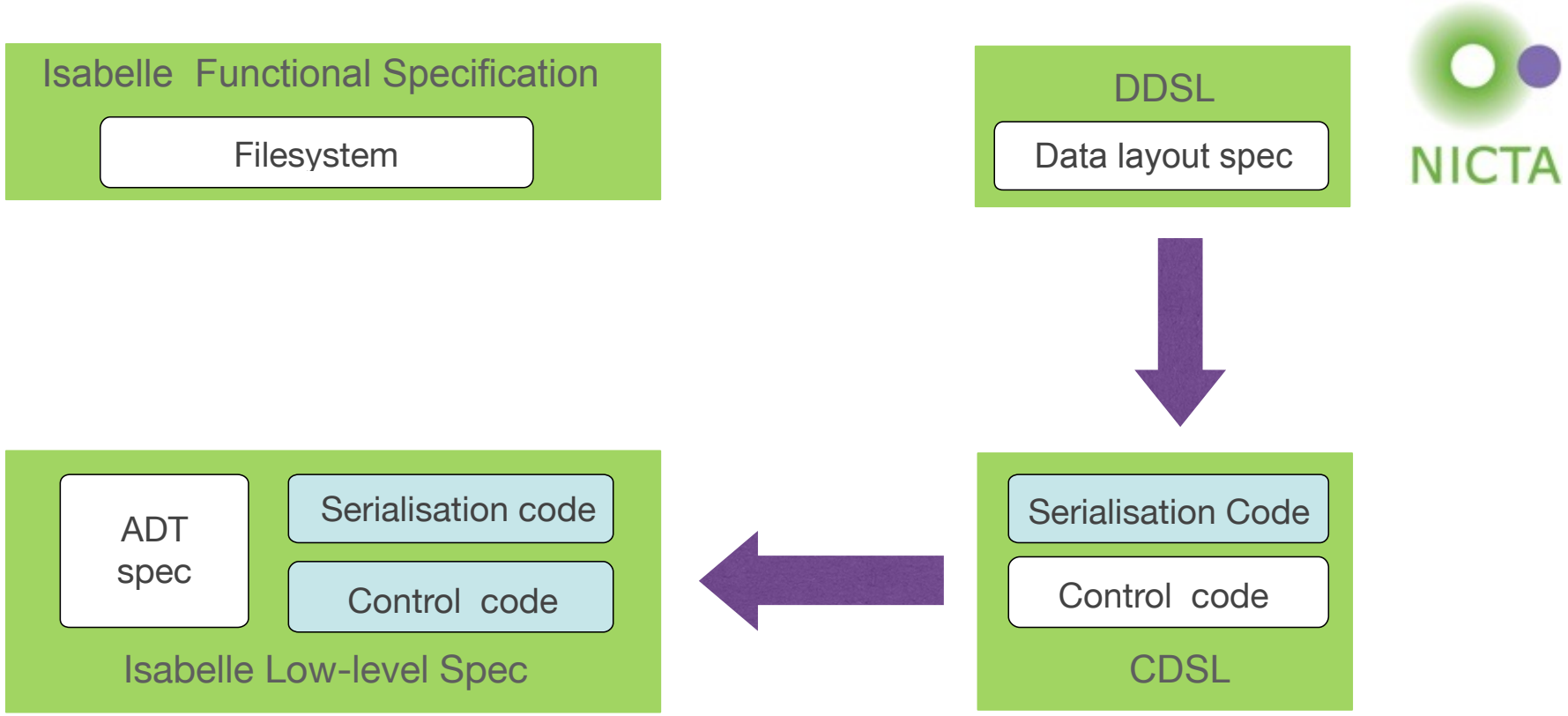
Serialisation Code
Control code
CDSL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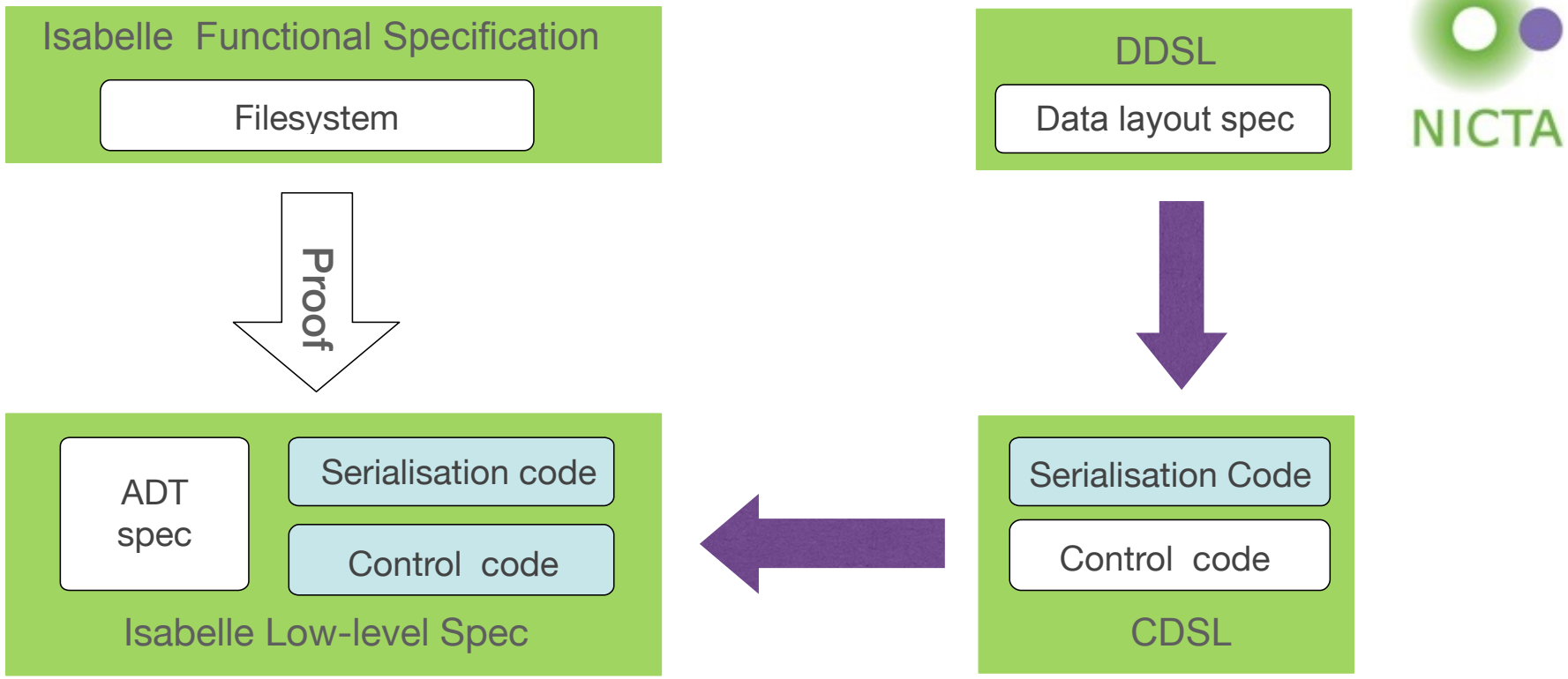
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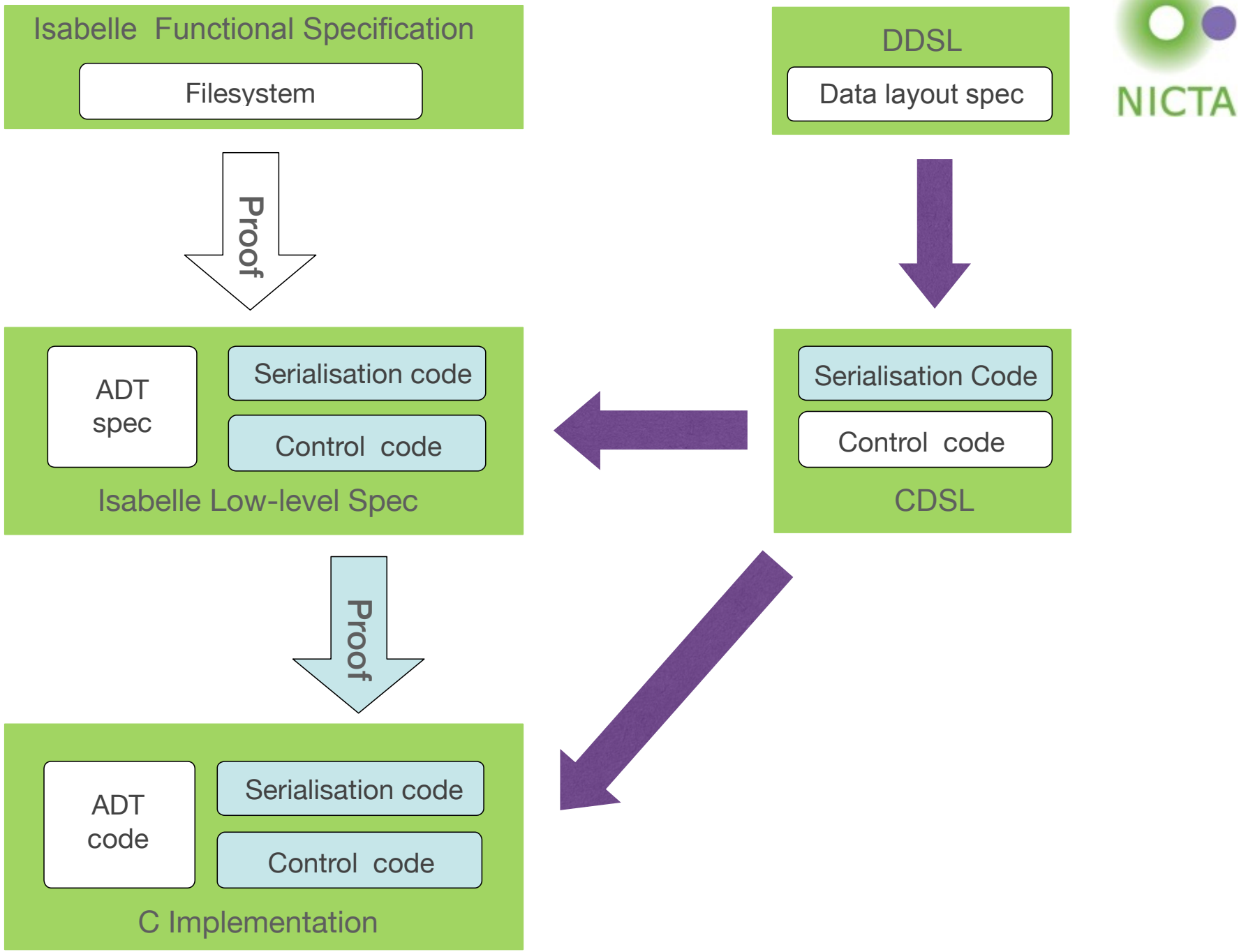
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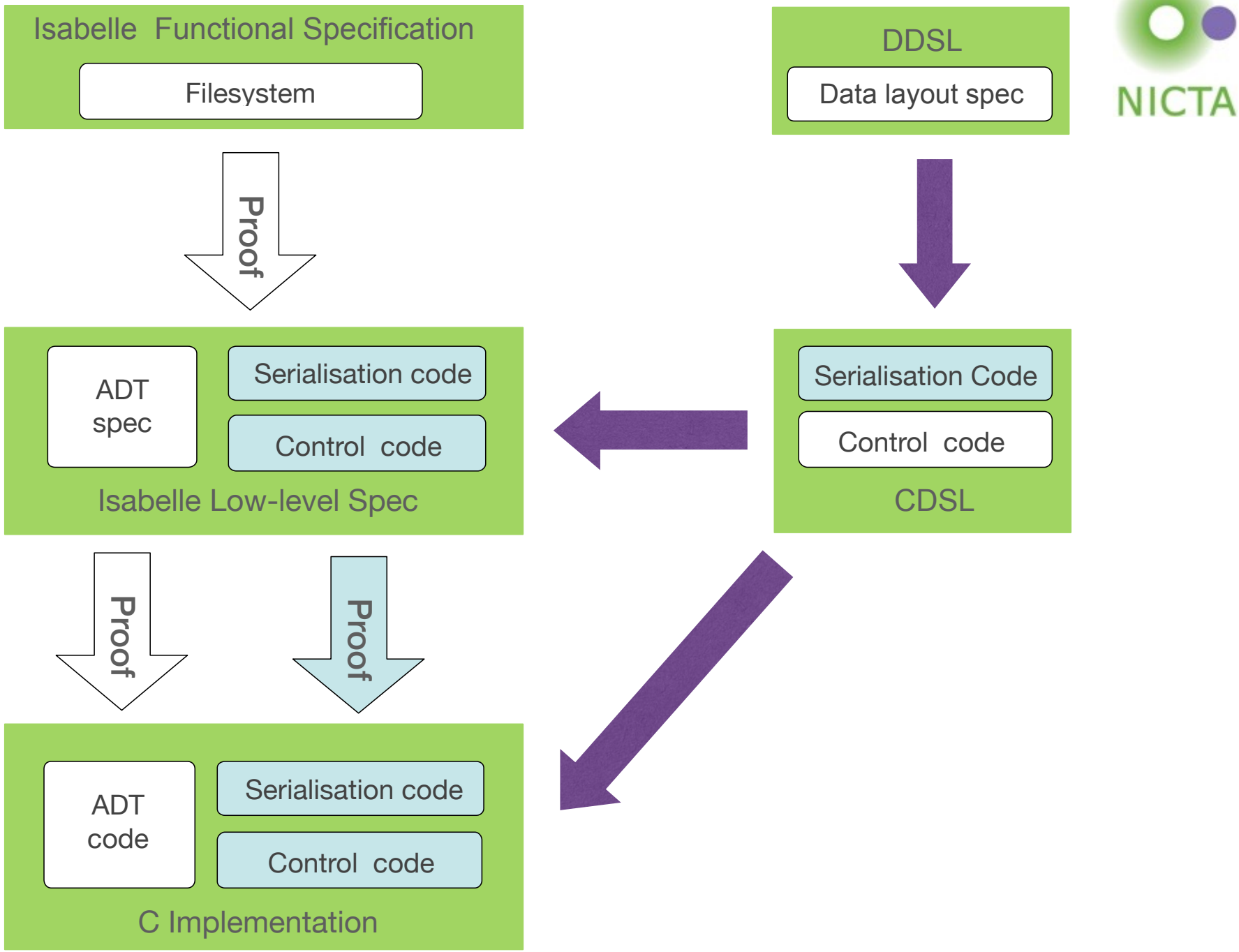
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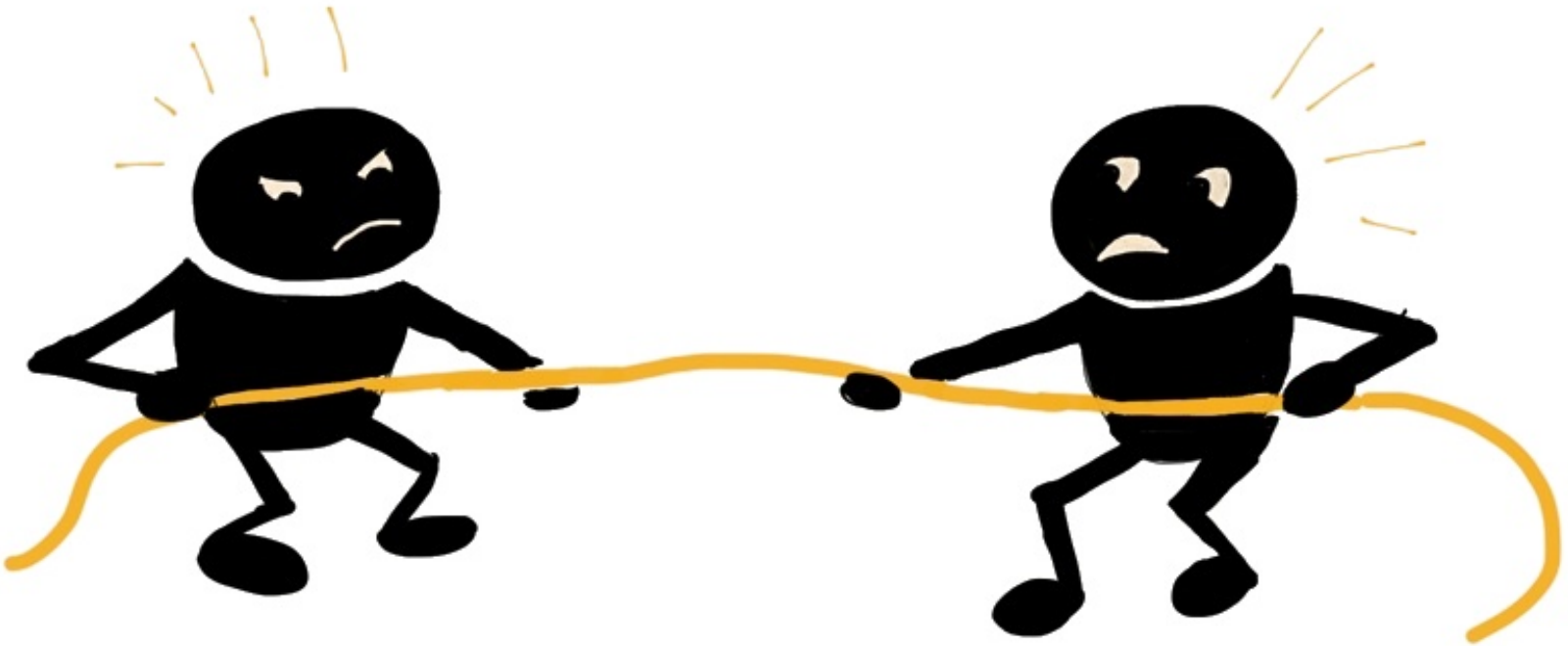
Design of the Control DSL

NICTA



Systems:
- efficiency
- destructive updates
- expressiveness
- concise

Verification:
- controlled side effects
- memory & type safety
- termination
- equational reasoning

Design of the Control DSL

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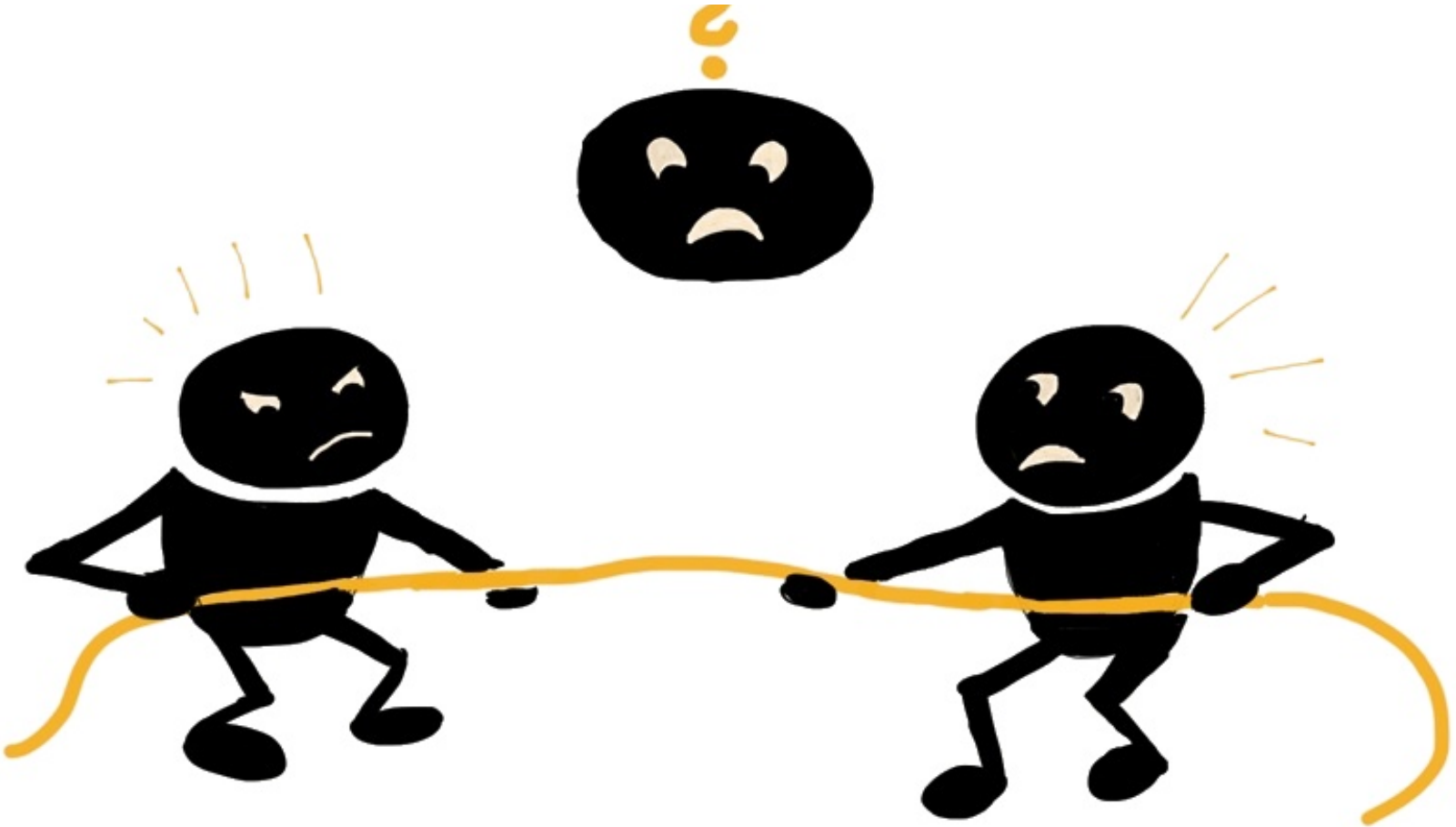

Systems:
- efficiency
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Verification:
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Updates

NICTA

```
f(x) = let
  x1 = update1 x
  x2 = update2 x1
in x2
```

Updates

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```
f(x) = let
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x no longer used

Updates

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Updates

NICTA

```
f(x) = let
  x1 = update!1 x
  x2 = update2 x1
in x2
```

Updates

NICTA

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f(x) = let
  x1 = update!1 x
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in x2
```

x_1 no longer used

Updates

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x_1 no longer used

Updates

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```

Memory Management

NICTA

```
f(x) = let
   (x', xc) = copy x
   (ok, x") = foo x'
in if ok
   then x"
   else xc
```

Memory Management

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f(x) = let
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Error: $\mathbf{x_c}$ not used

Error: **x"** not used

Memory Management

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f(x) = let
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Error: $\mathbf{x_c}$ not used

Error: **x"** not used

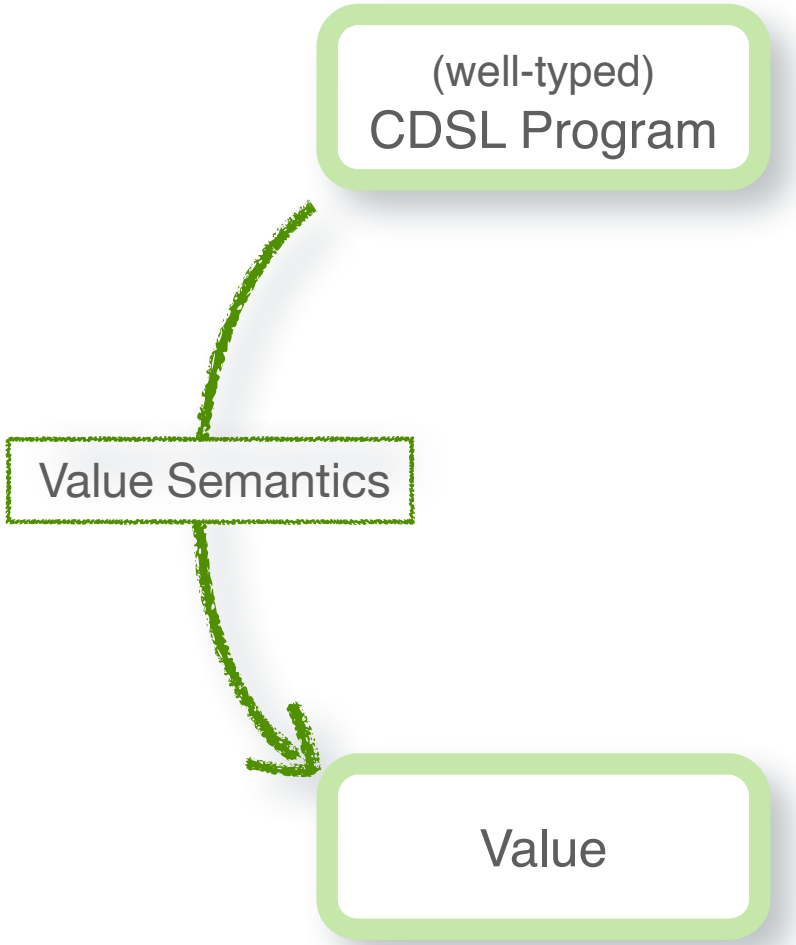
Memory Management

NICTA

```
f(x) = let
   (x', xc) = copy x
   (ok, x") = foo x'
in if ok
    then free xc ; x"
    else free x" ; xc
```

Value and Update Semantics of CDSL

Value and Update Semantics of CDSL

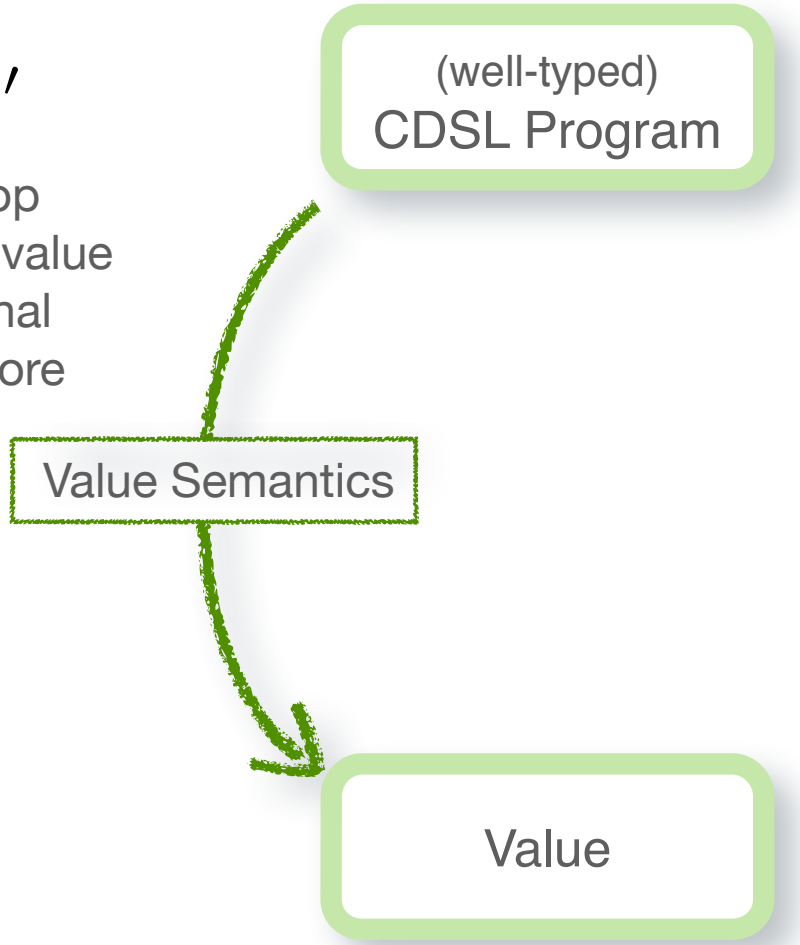


Value and Update Semantics of CDSL

NICTA

$$\Gamma \vdash e \mapsto e'$$

- `free` is a no-op
- Everything by value
- Purely functional
- No mutable store



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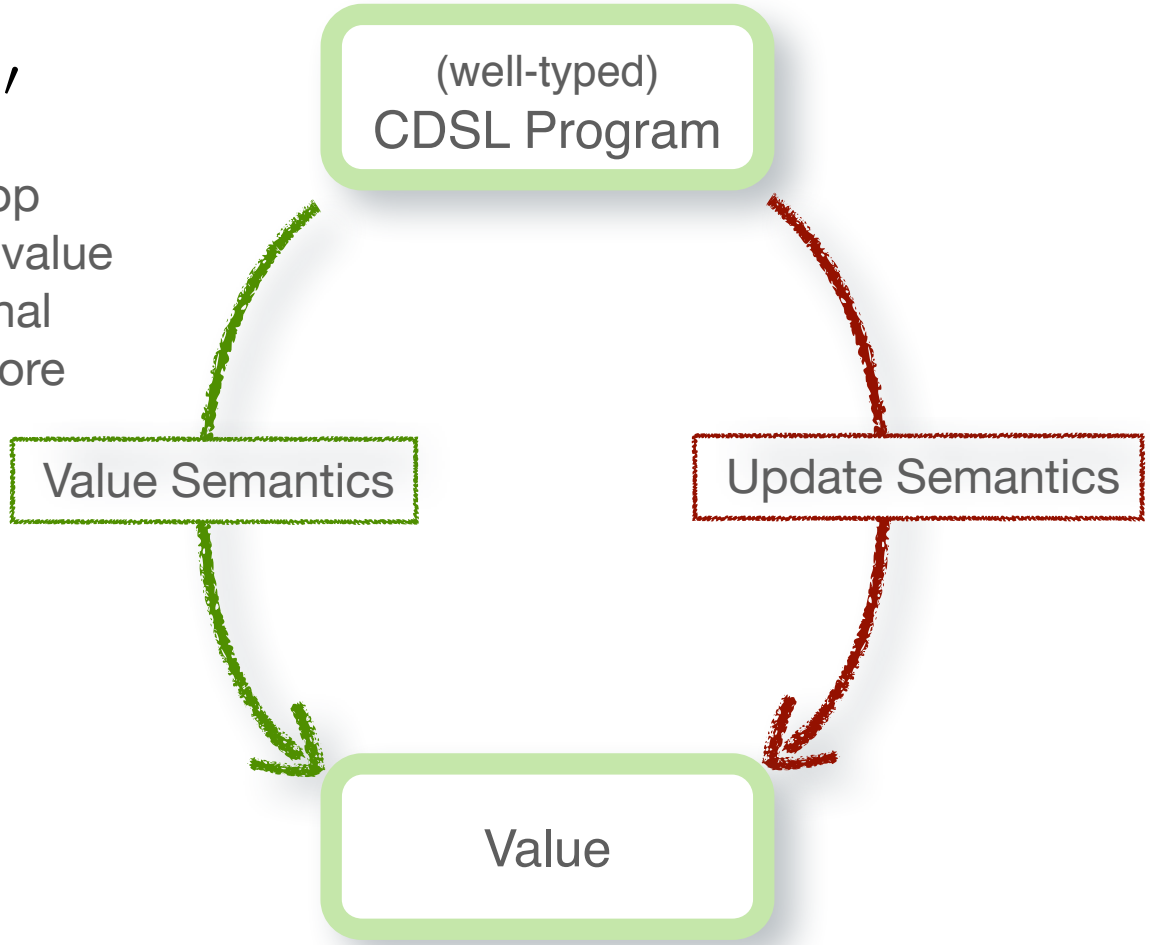

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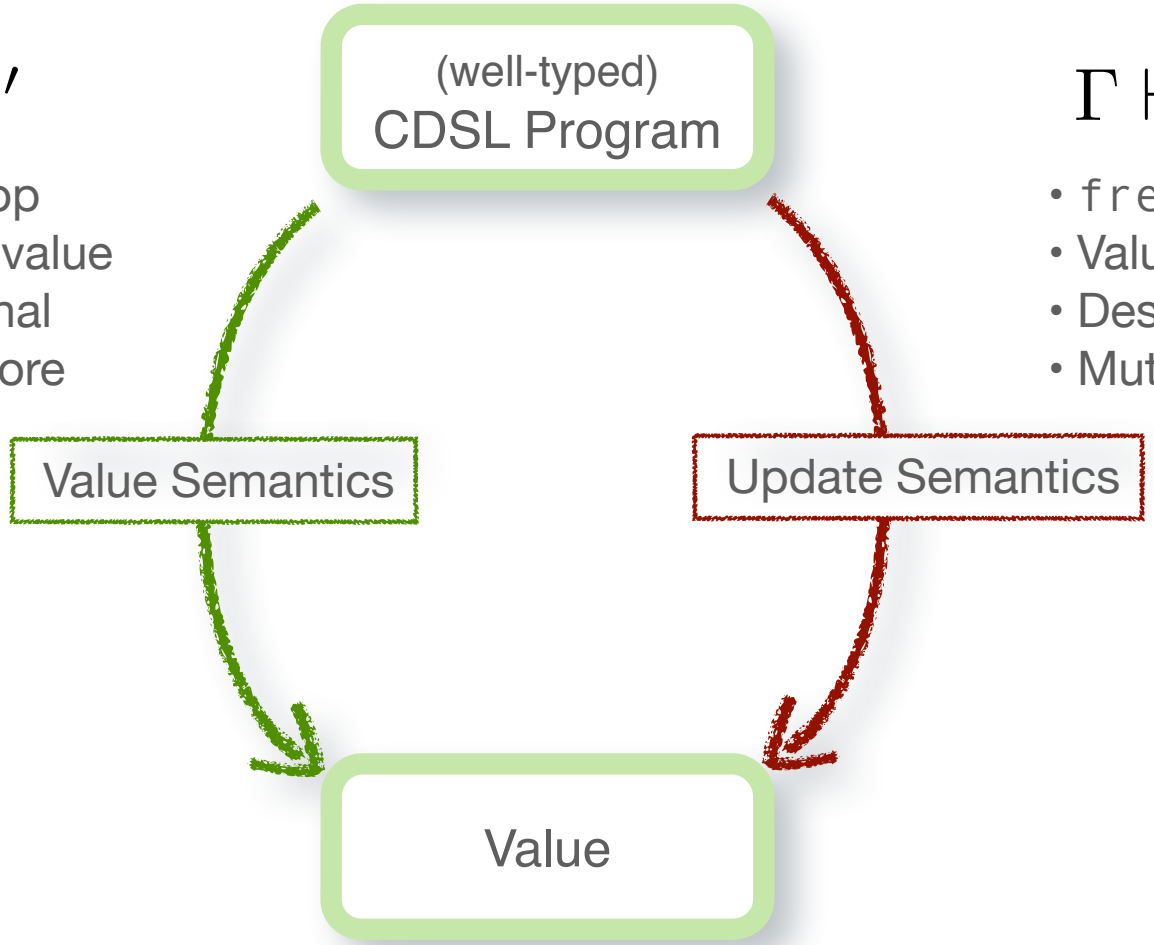

$\Gamma \vdash \sigma, e \mapsto \sigma', e'$

- `free` operates on a store
- Values can be store refs
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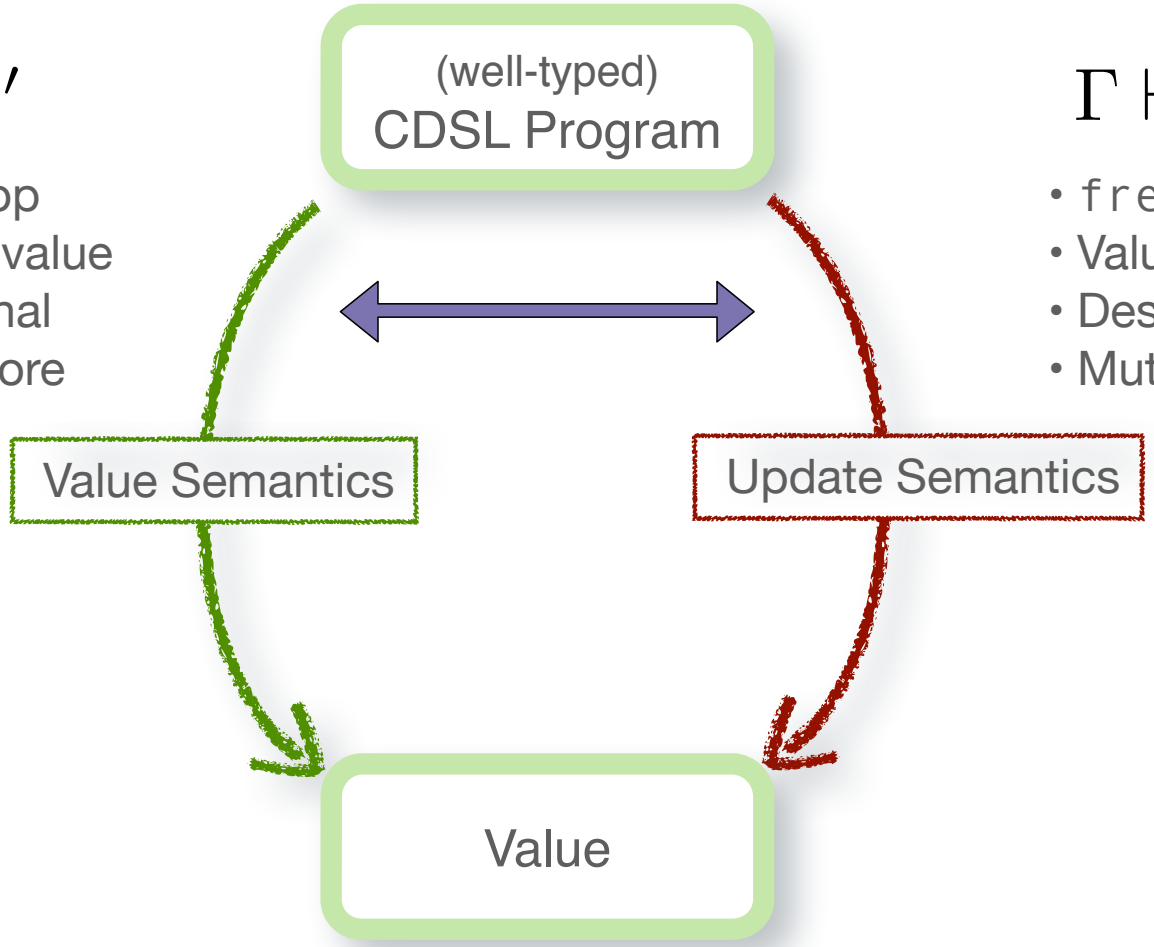

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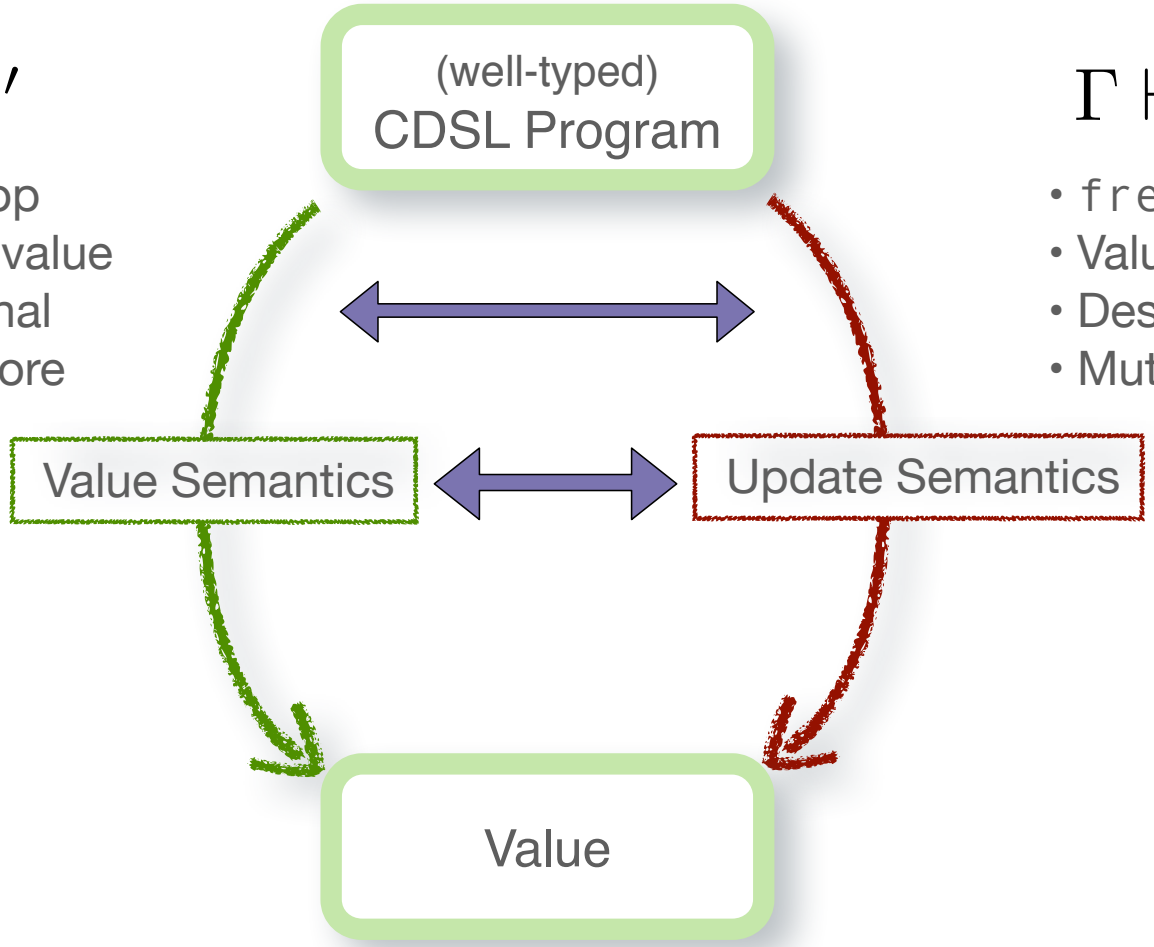

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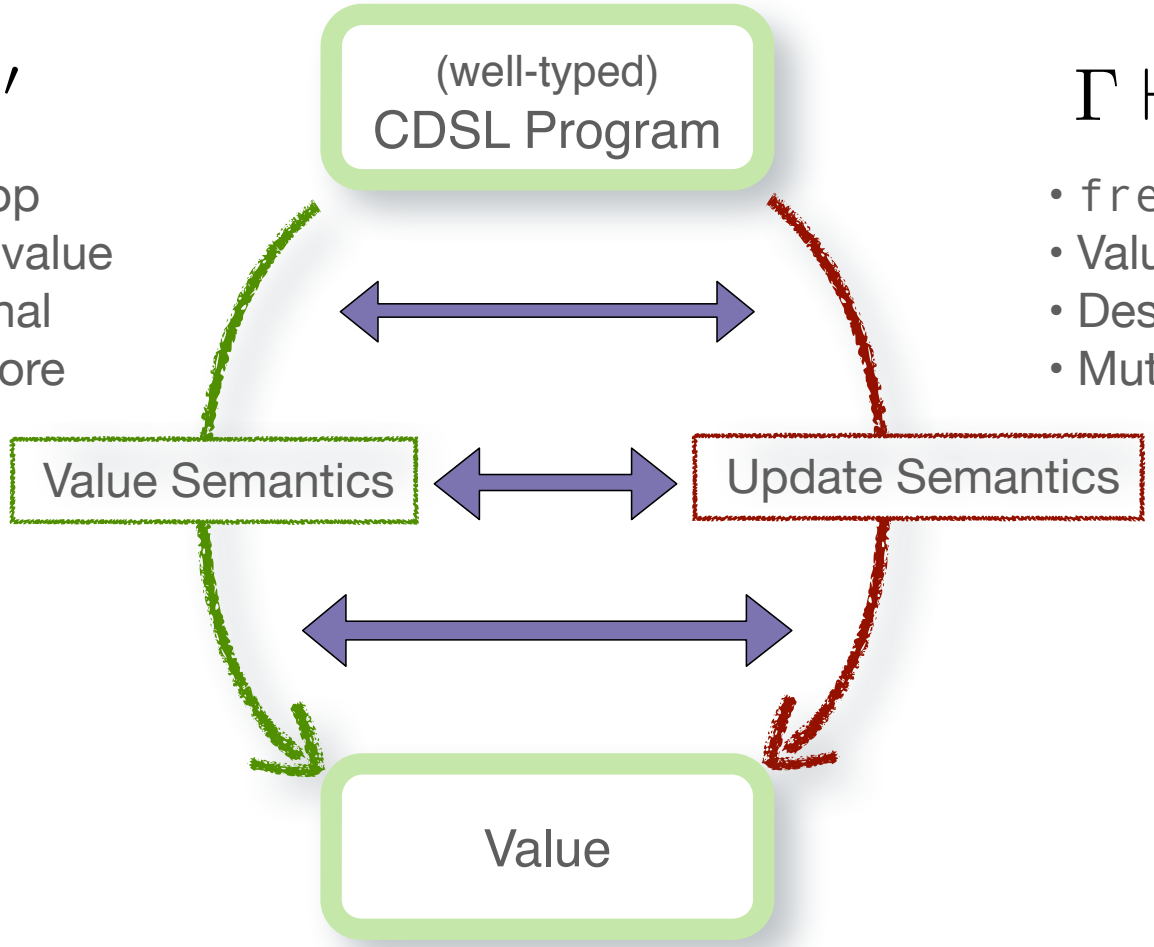

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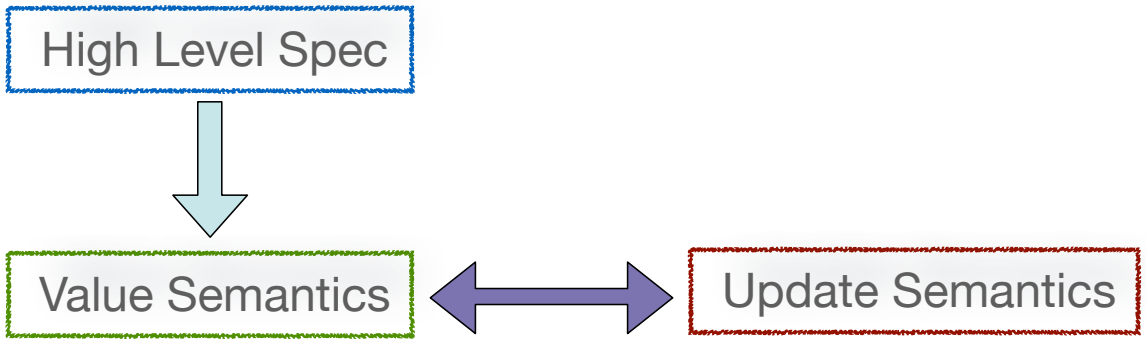

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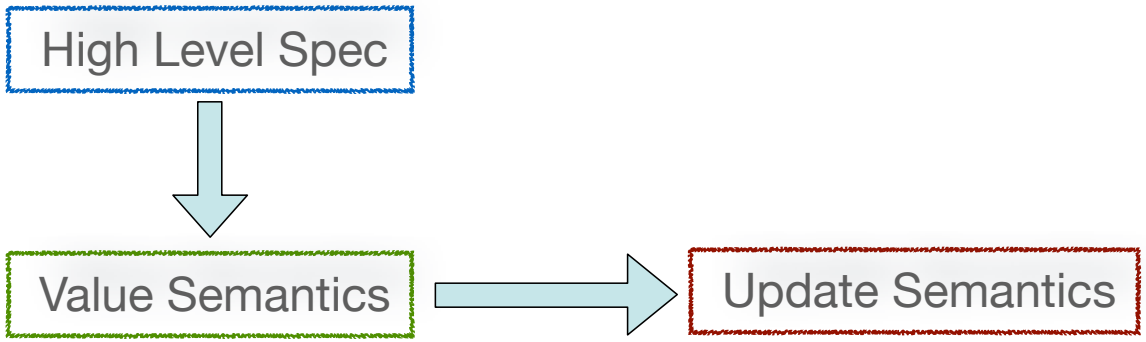

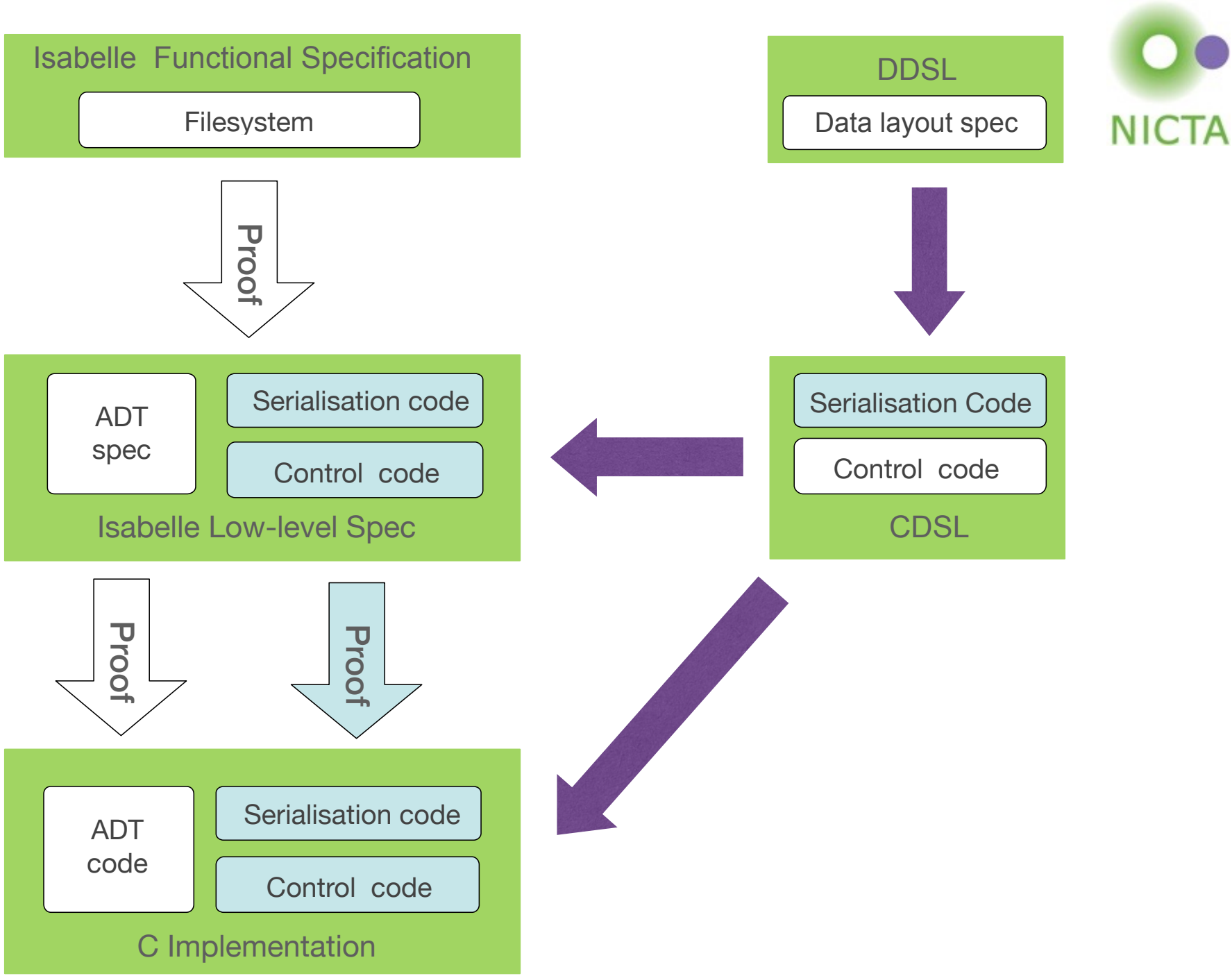
Isabelle Functional Specification
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DDSL
Data layout spec
NICTA
Proof
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Serialisation code
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Serialisation Code
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C Implementation


```
data SObj = {
   x :: Ple32,
   y :: U8
}
```

NICTA

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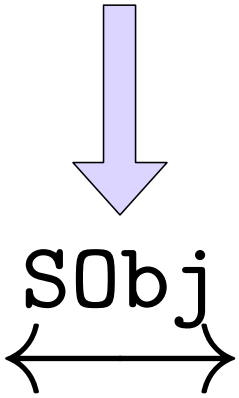

Design of the Data Description Language

NICTA

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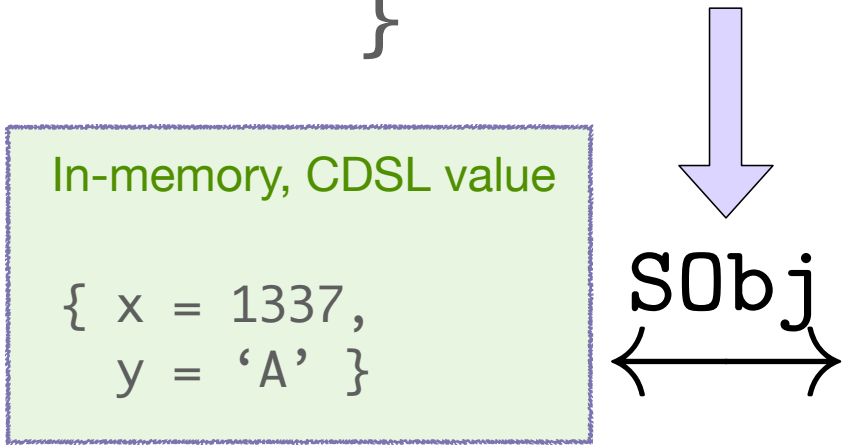

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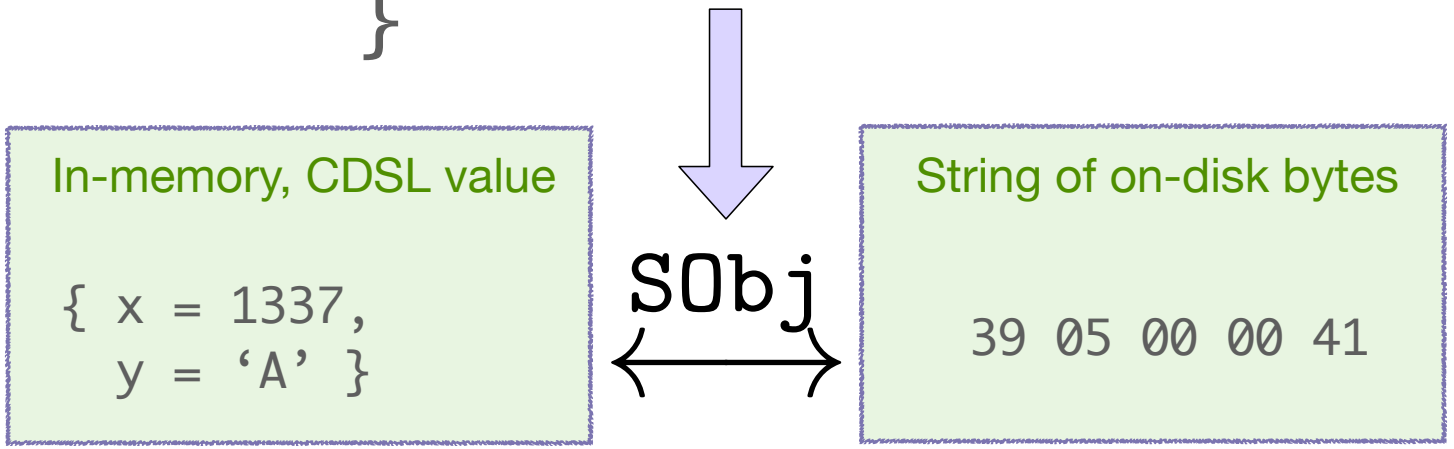

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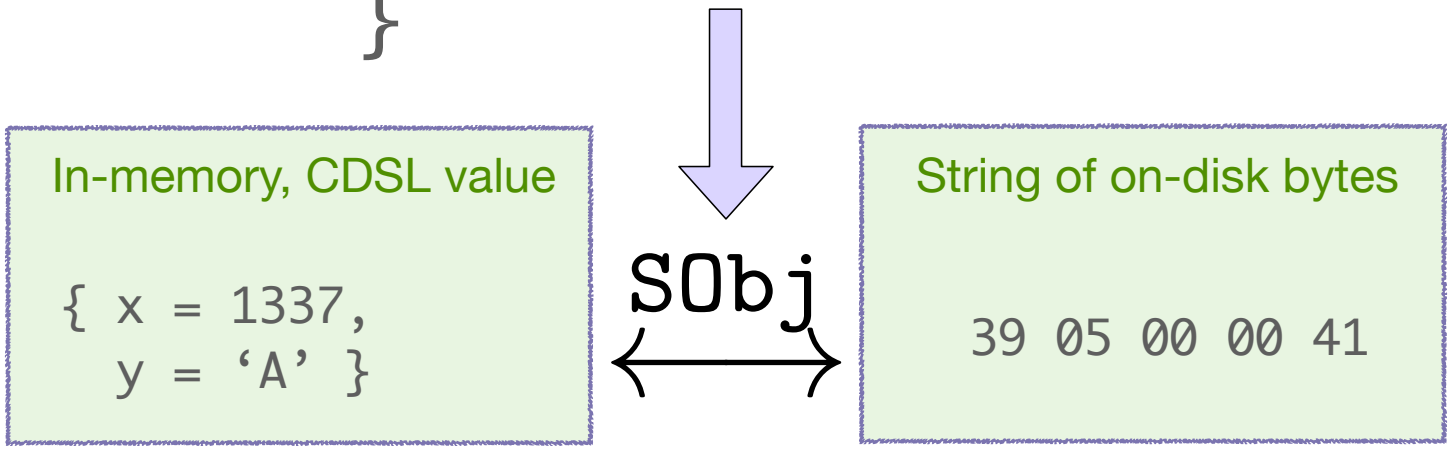

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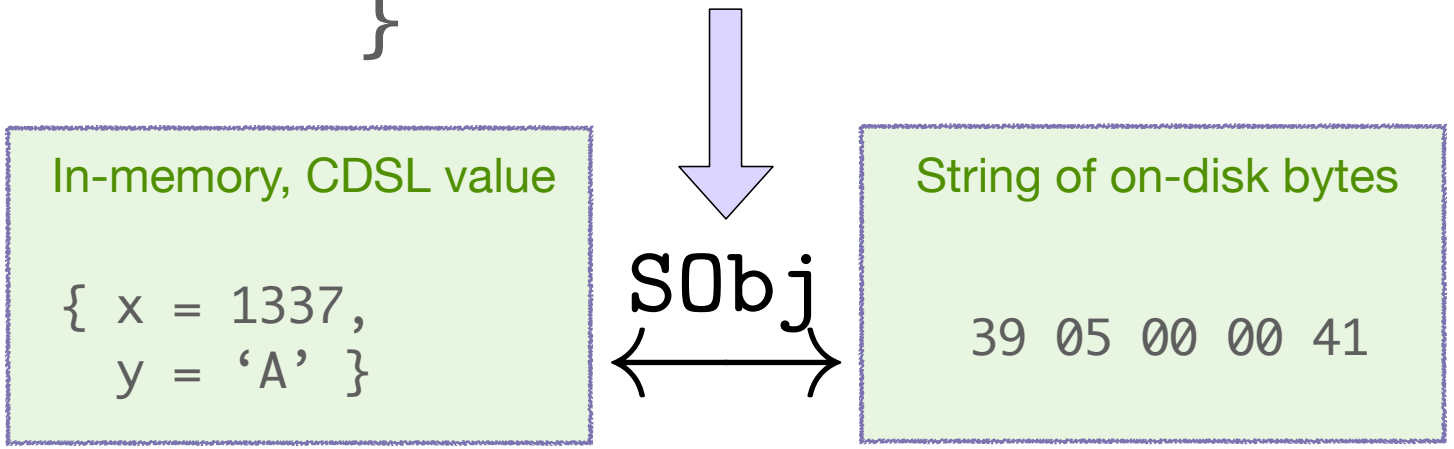


Design of the Data Description Language

NICTA

Existing DDLs

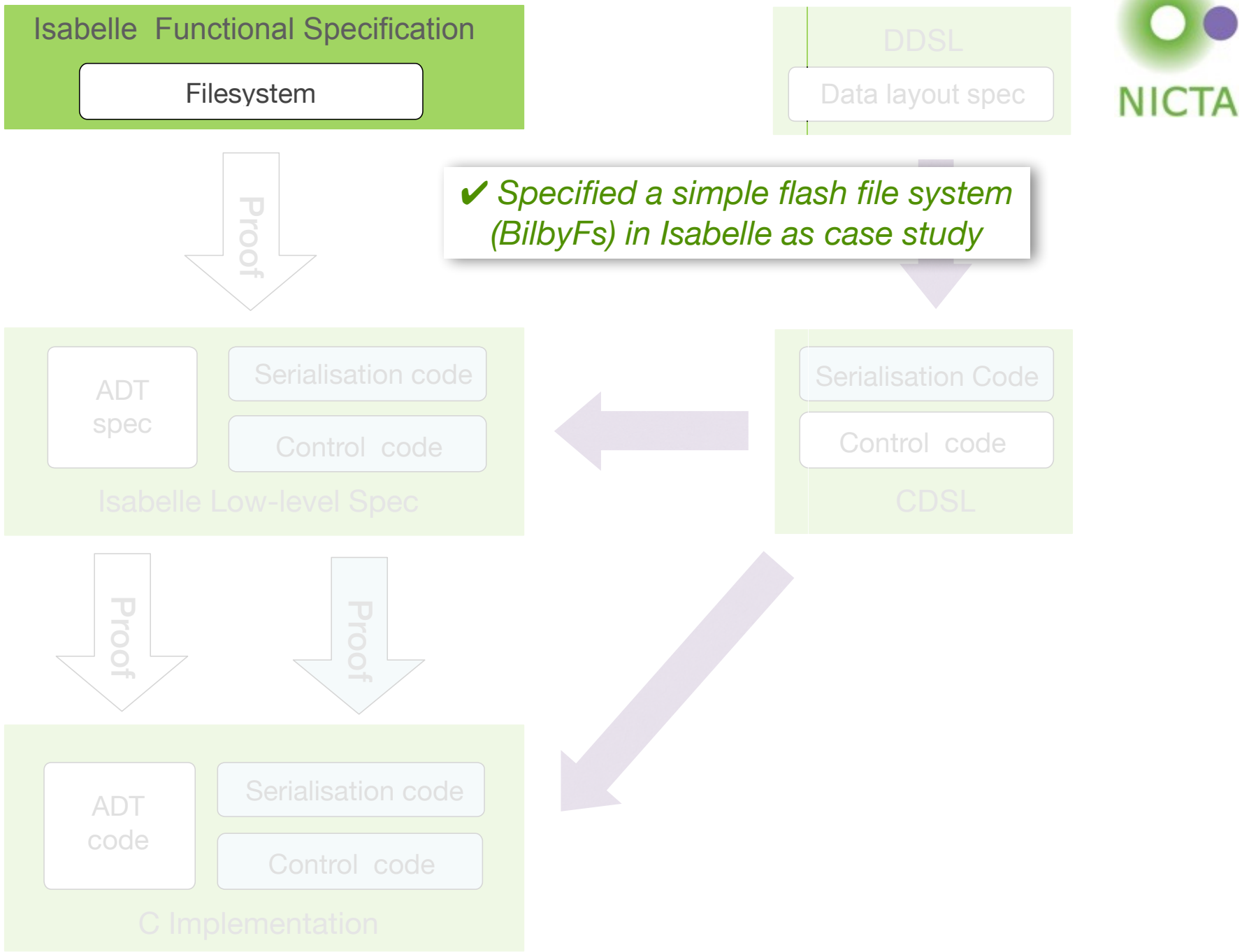
how to specify data structures and data layout

how to express constraints on the values of the data structures

what and how to check statically

Existing verification tools

how to handle verification for tagged bitfield serialisation & de-serialisation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Filesystem
DDSL
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Proof
✔ Specified a simple flash file system (BilbyFs) in Isabelle as case study
ADT spec
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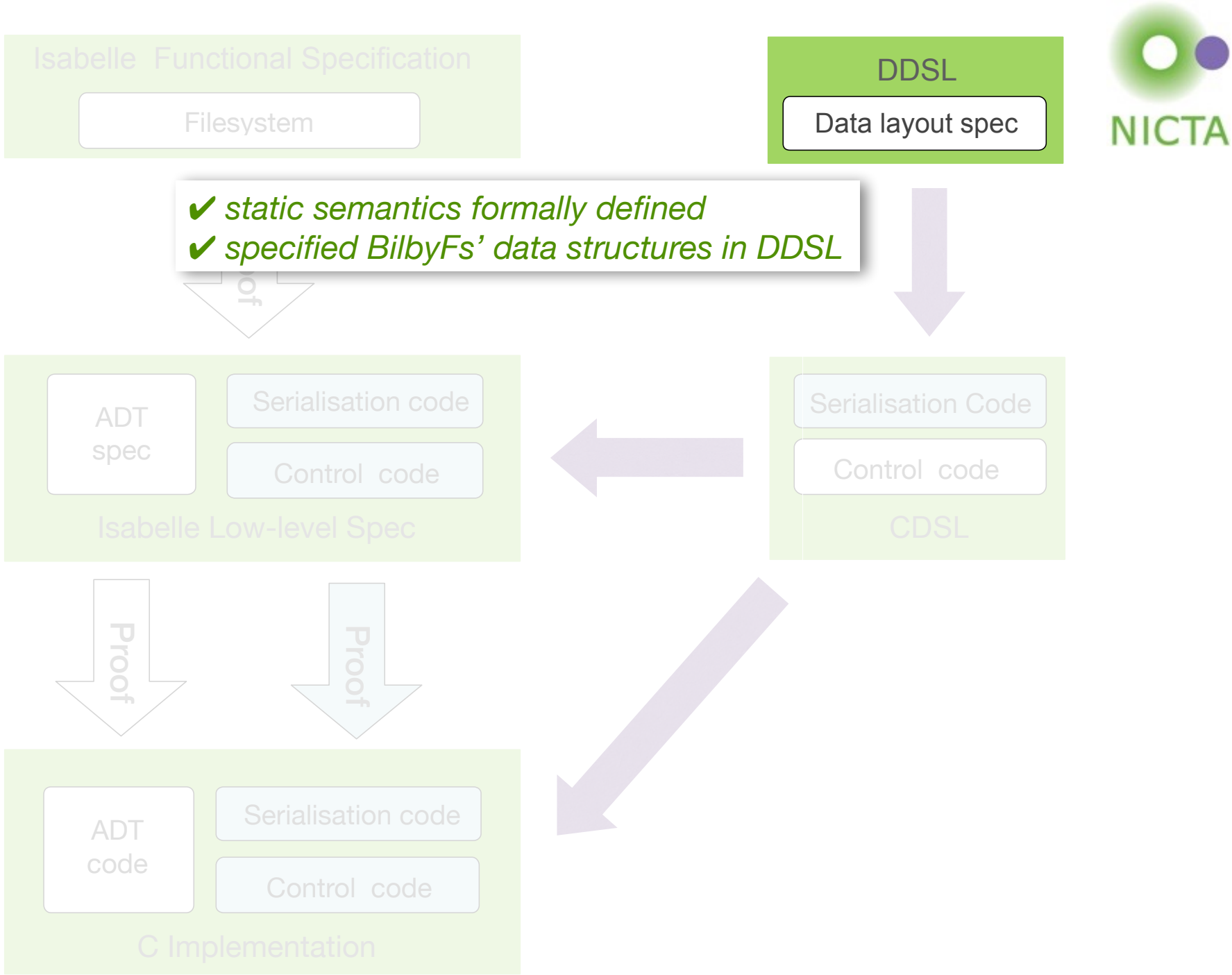
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Data layout spec
✔ static semantics formally defined
✔ specified BilbyFs' data structures in DDSL
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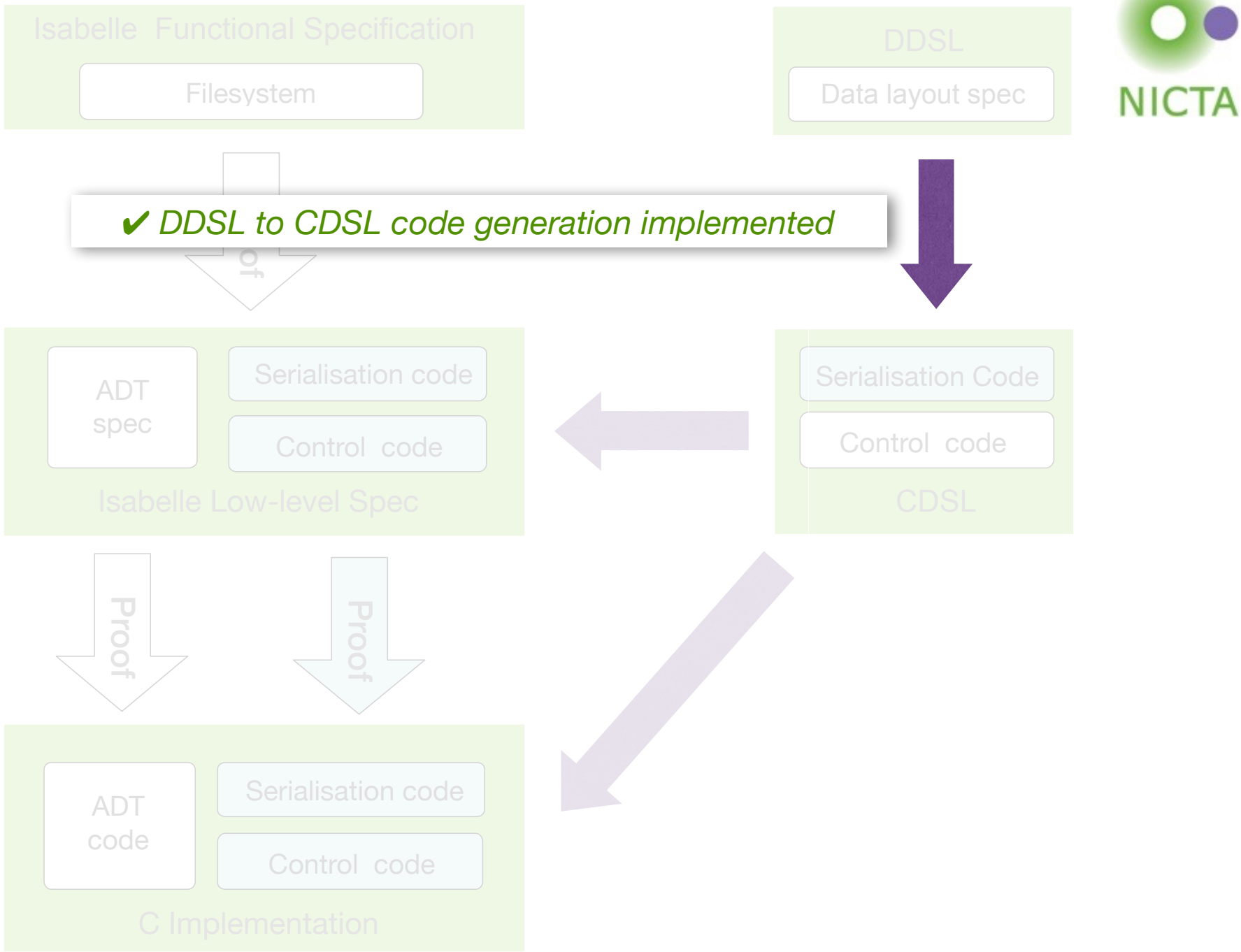
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✔ DDSL to CDSL code generation implemented
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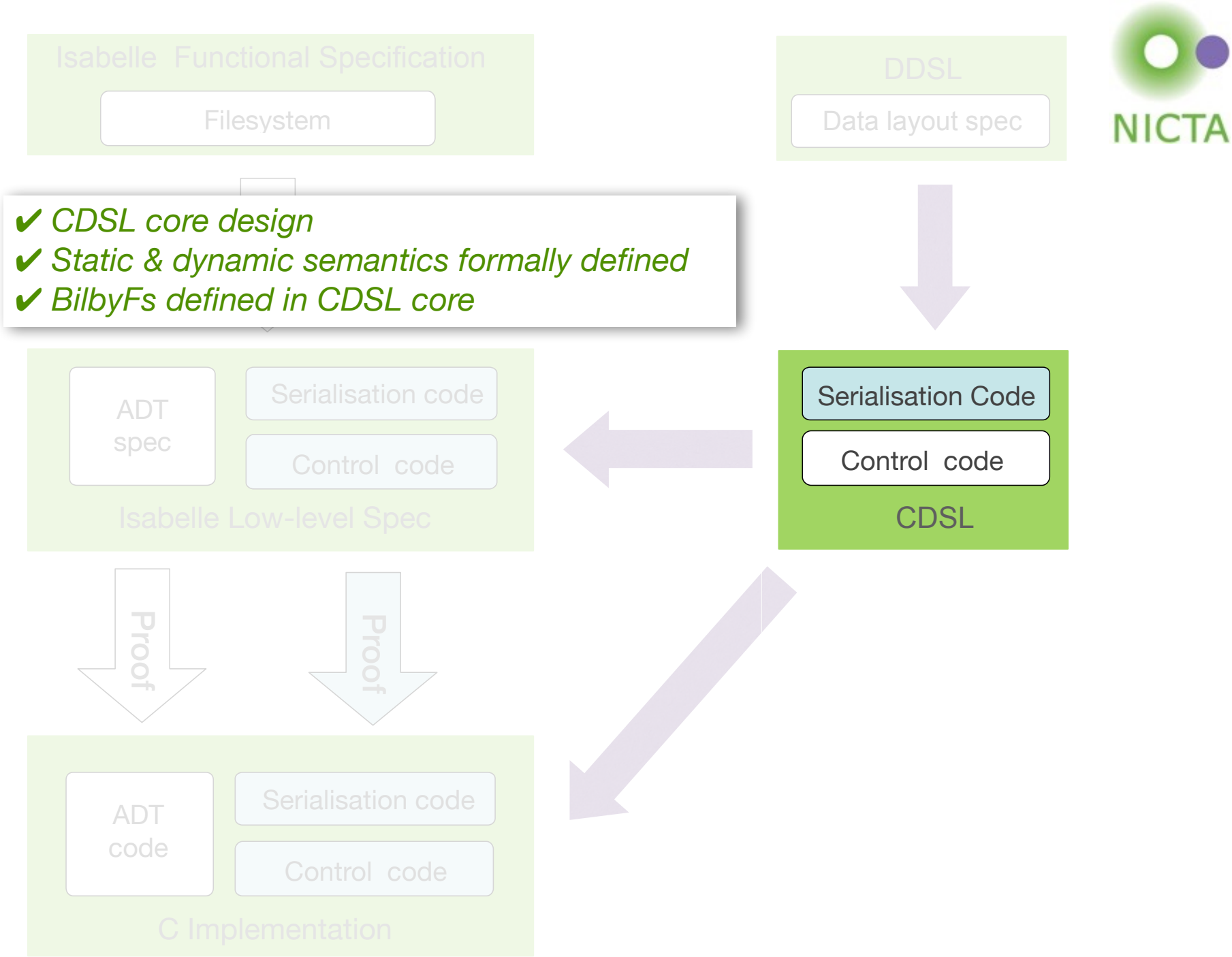
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Data layout spec
NICTA
✔ CDSL core design
✔ Static & dynamic semantics formally defined
✔ BilbyFs defined in CDSL core
ADT spec
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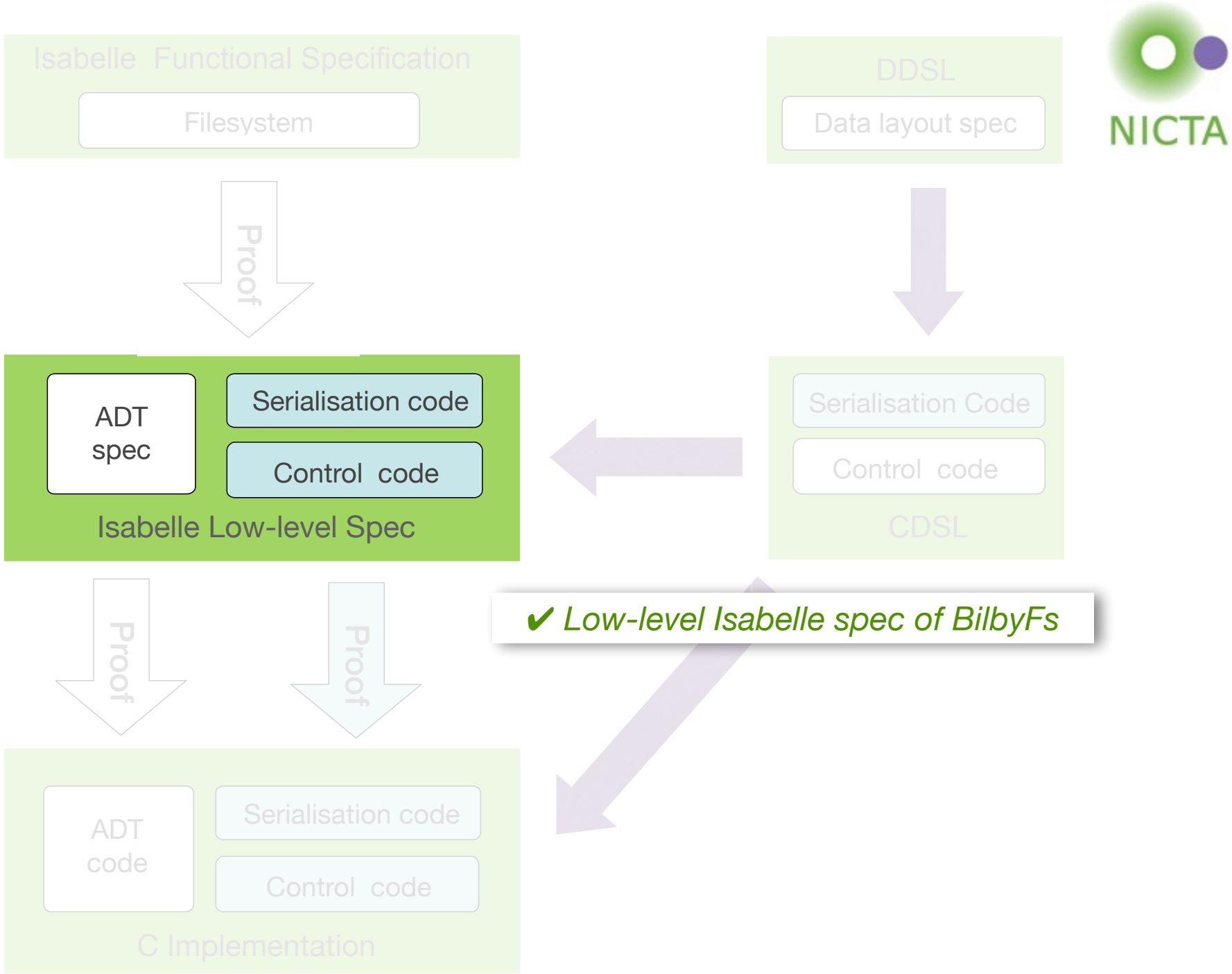
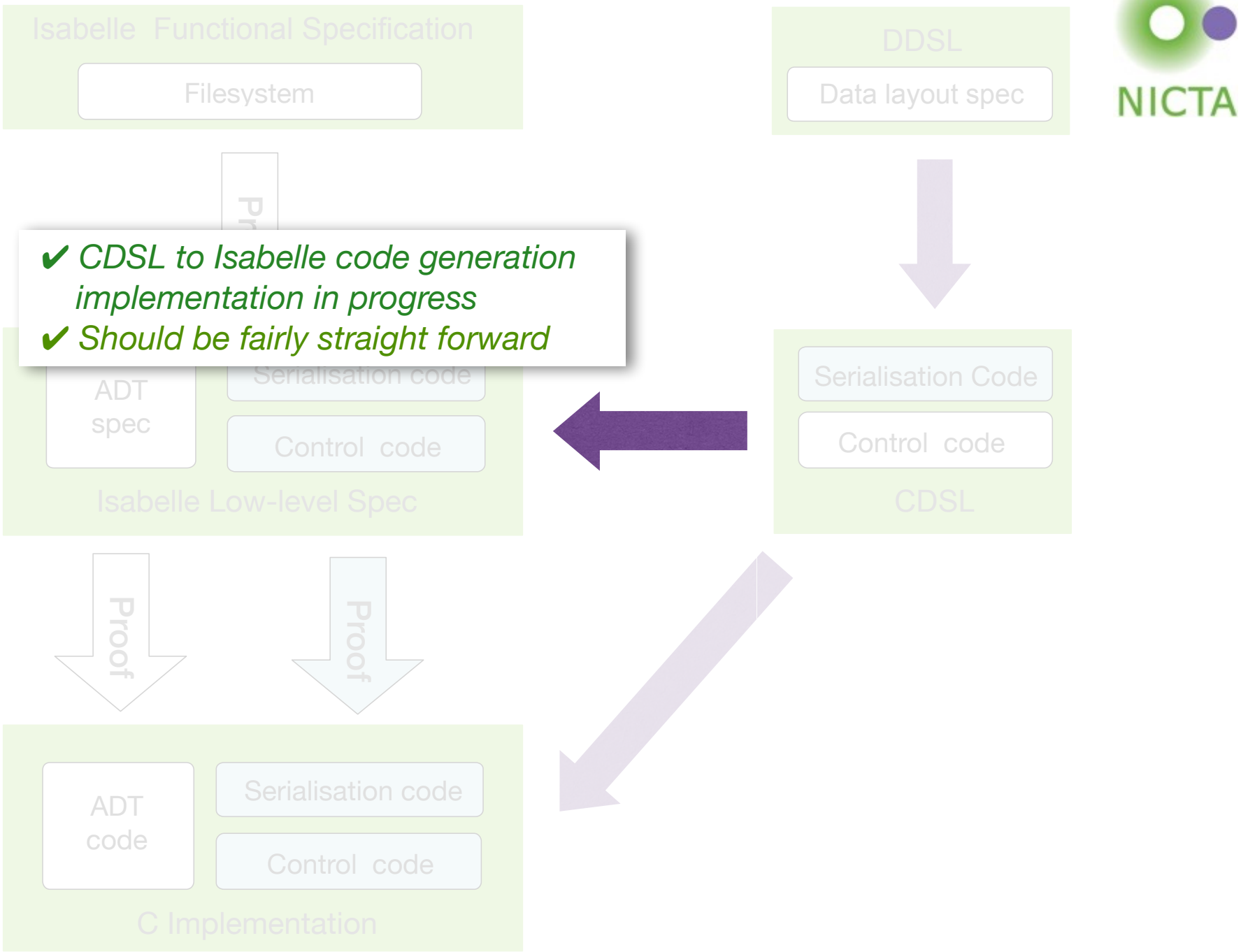
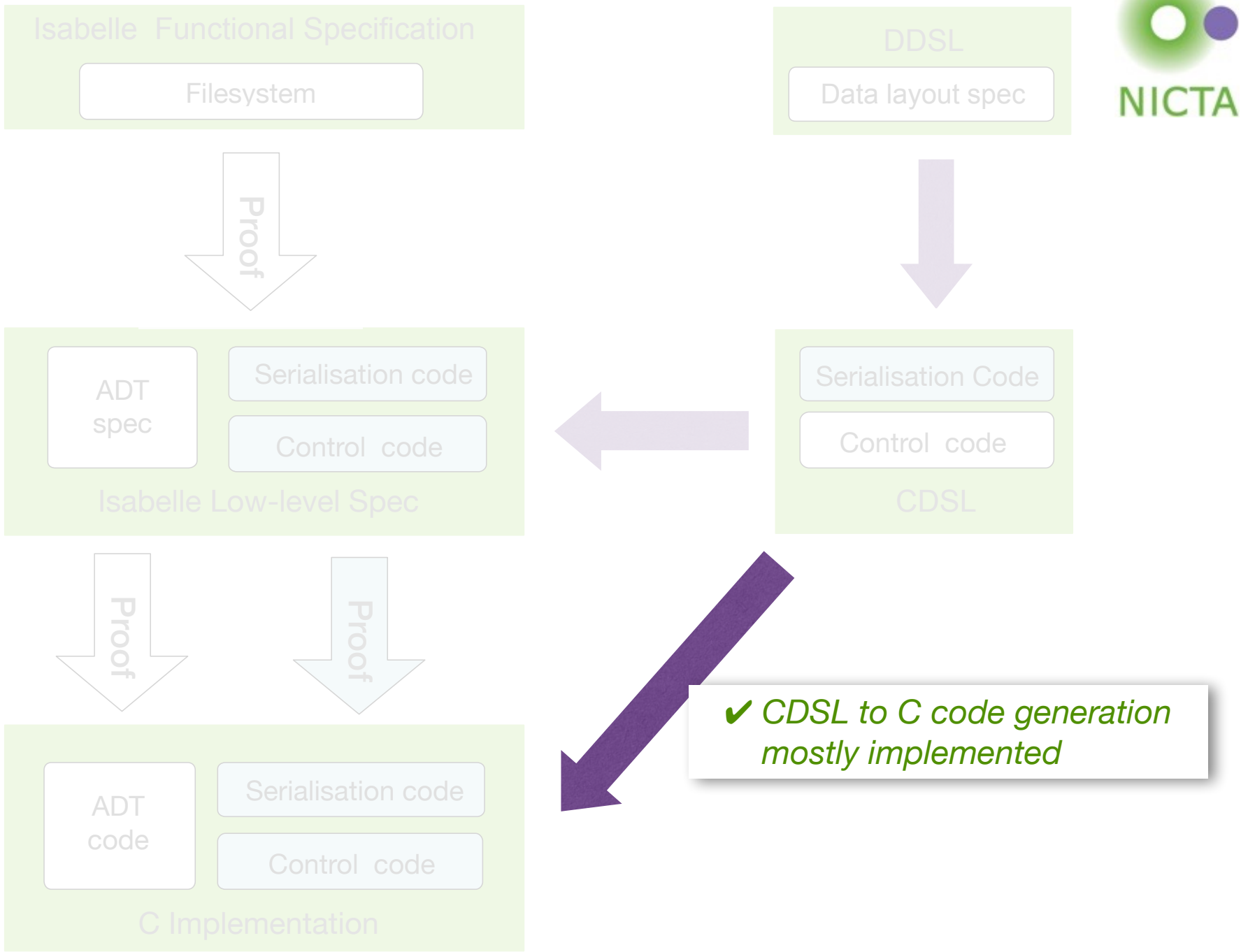
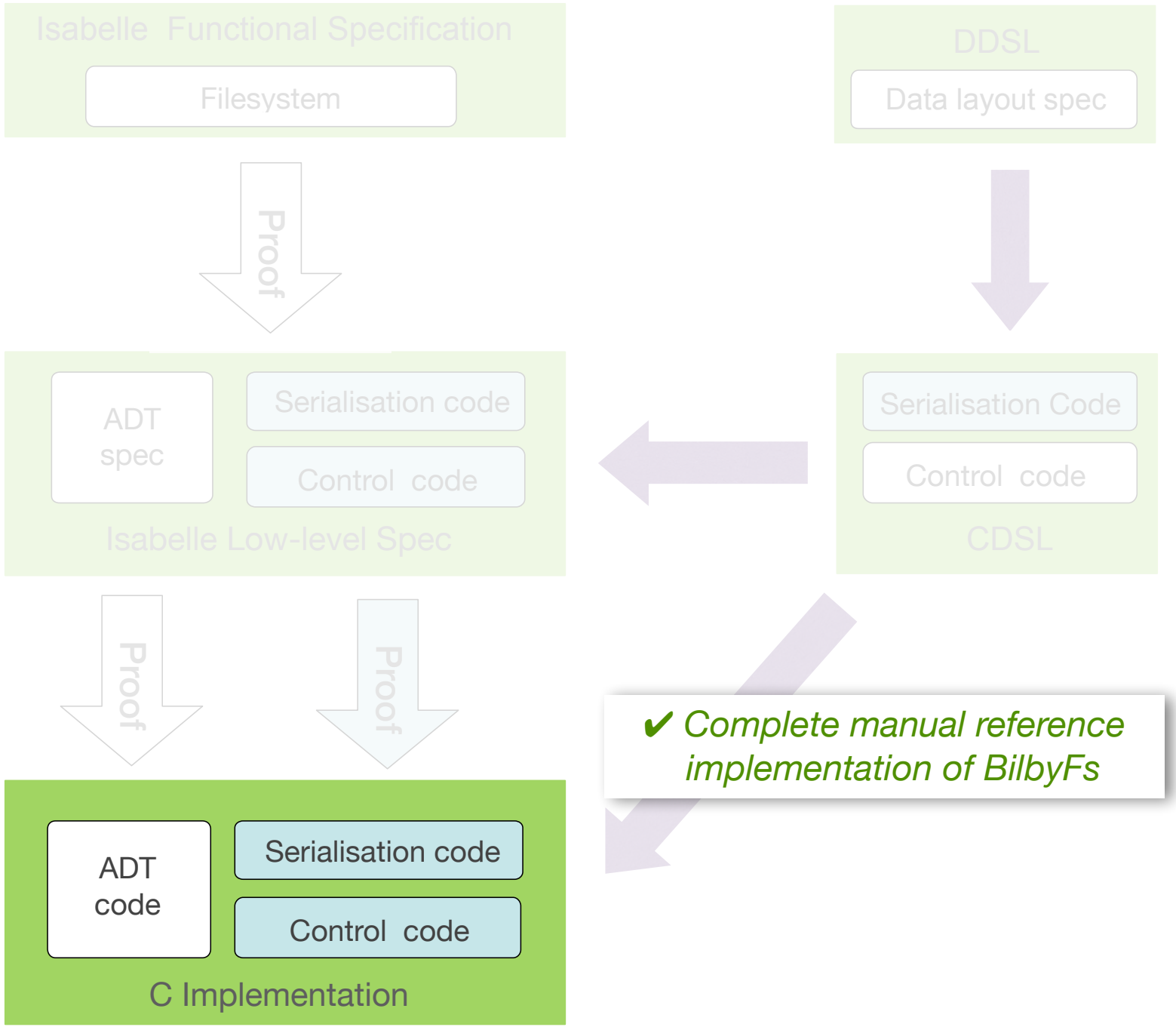
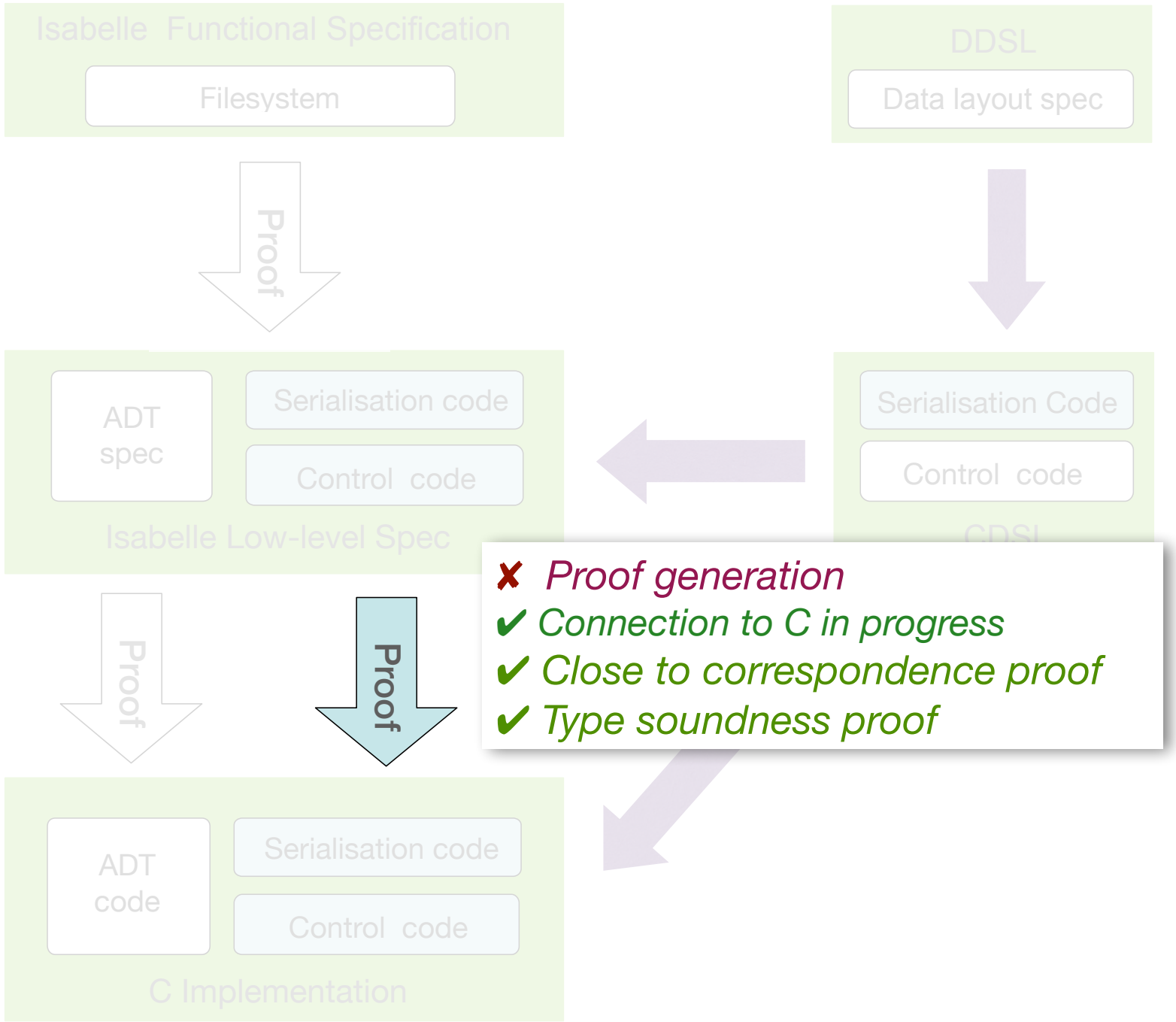
CDSL
Proof
Proof
ADT code
Serialisation code
Control code
C Implementation


Isabelle Functional Specification
Filesystem
DDSL
Data layout spec
Proof
ADT spec
Serialisation code
Control code
Isabelle Low-level Spec
Serialisation Code
Control code
CDSL
✔ Low-level Isabelle spec of BilbyFs
Proof
Proof
ADT code
Serialisation code
Control code
C Implementation


Isabelle Functional Specification
Filesystem
DDSL
Data layout spec
✔ CDSL to Isabelle code generation implementation in progress
✔ Should be fairly straight forward
ADT spec
Serialisation code
Control code
Isabelle Low-level Spec
Serialisation Code
Control code
CDSL
Proof
Proof
ADT code
Serialisation code
Control code
C Implementation


Isabelle Functional Specification
Filesystem
DDSL
Data layout spec
NICTA
Proof
ADT spec
Serialisation code
Control code
Isabelle Low-level Spec
Serialisation Code
Control code
CDSL
Proof
Proof
ADT code
Serialisation code
Control code
C Implementation
✔ CDSL to C code generation mostly implemented


Isabelle Functional Specification
Filesystem
DDSL
Data layout spec
Proof
ADT spec
Serialisation code
Control code
Isabelle Low-level Spec
Serialisation Code
Control code
CDSL
Proof
Proof
ADT code
Serialisation code
Control code
C Implementation
✔ Complete manual reference implementation of BilbyFs


Isabelle Functional Specification
Filesystem
DDSL
Data layout spec
Proof
ADT spec
Serialisation code
Control code
Isabelle Low-level Spec
Serialisation Code
Control code
DDSL
Proof
Proof
✘ Proof generation
✔ Connection to C in progress
✔ Close to correspondence proof
✔ Type soundness proof
ADT code
Serialisation code
Control code
C Implementation

Thank You