A Data Layout Description Language for Cogent

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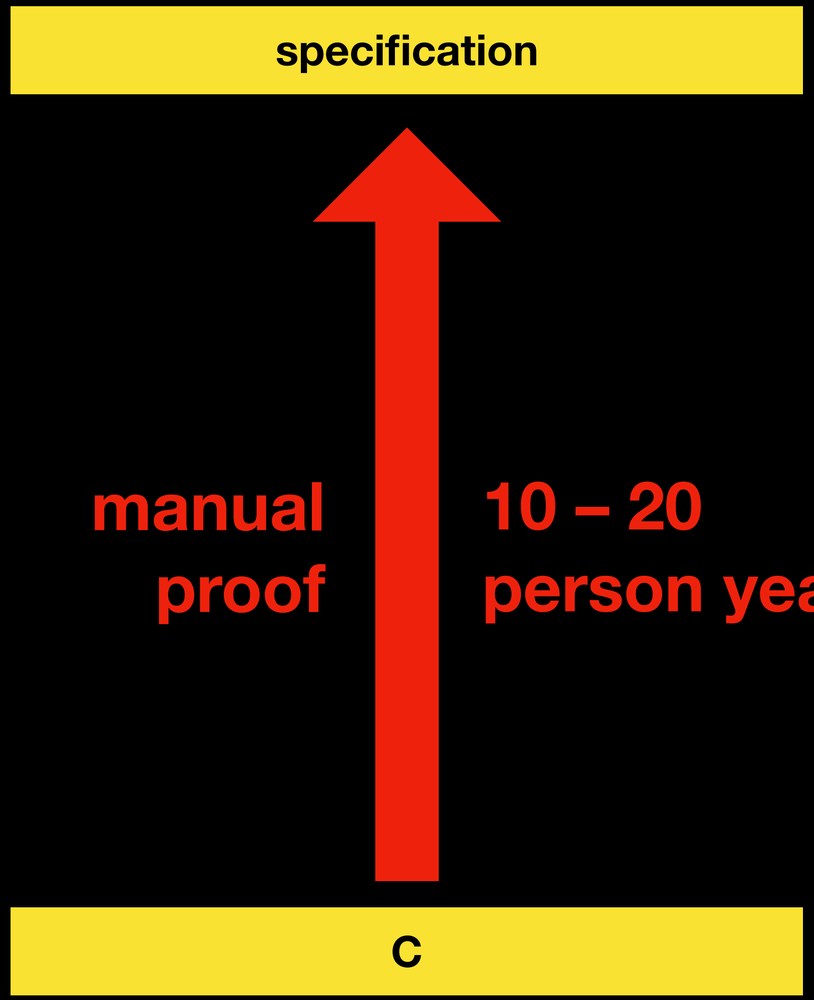
Cogent is a **programming language** and **certifying compiler** for building verified low-level systems

verified

proofs in
Isabelle HOL

seL4



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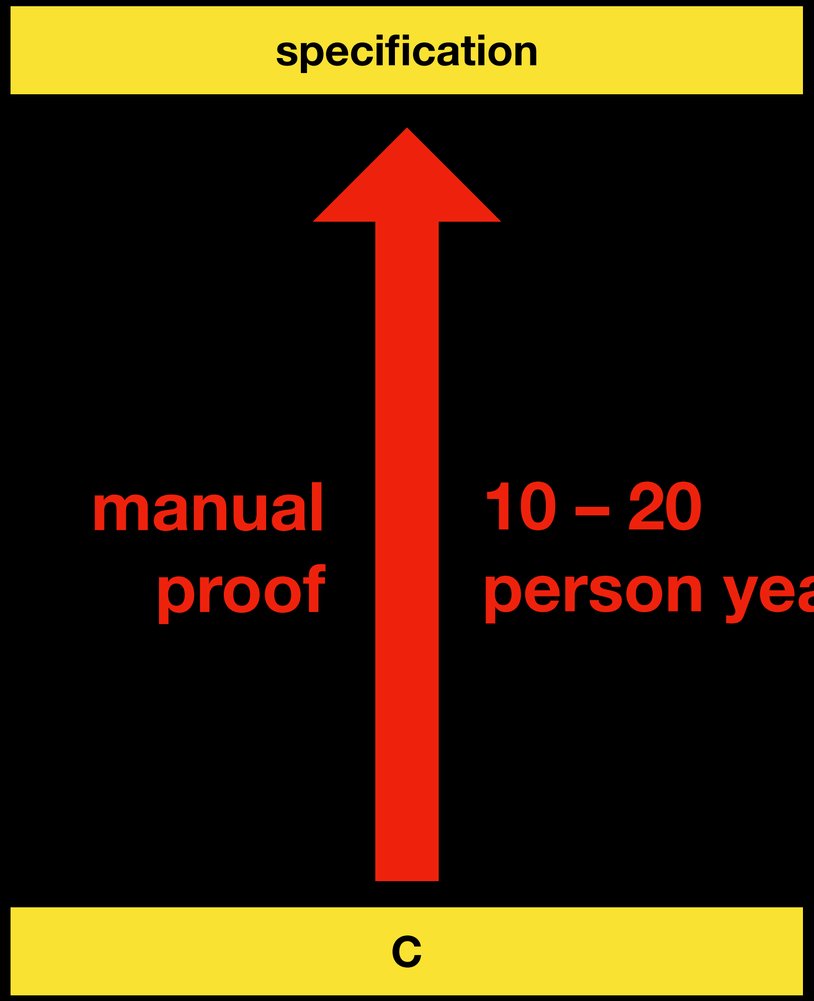

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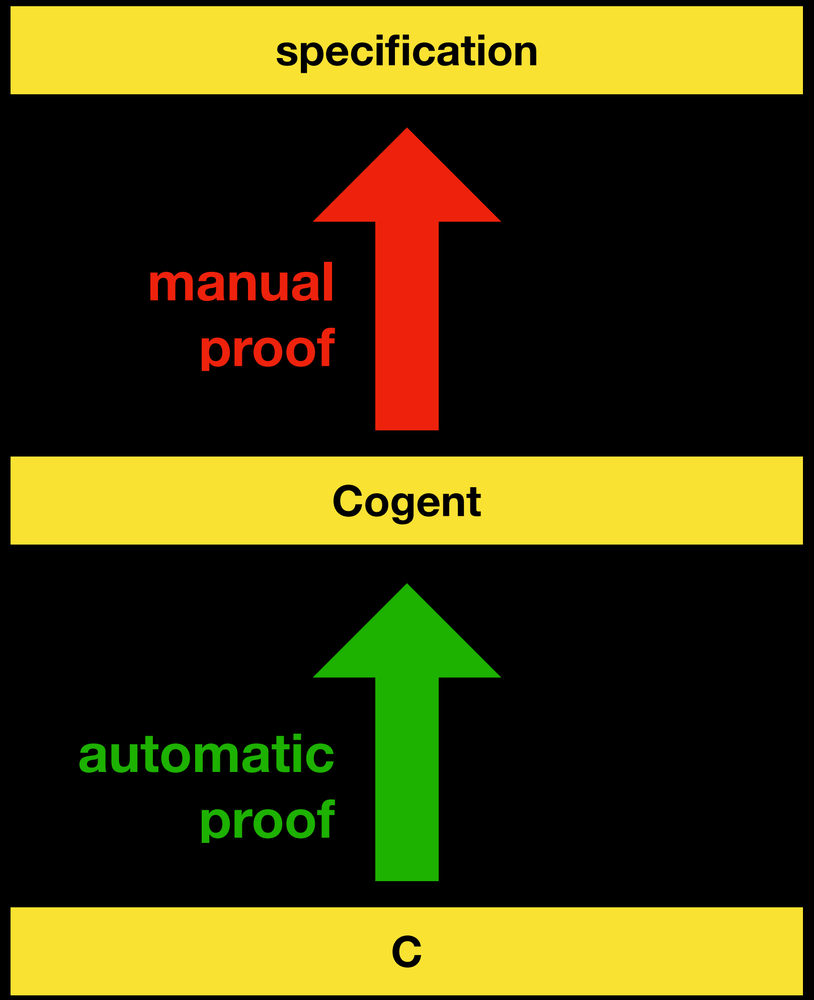

verified

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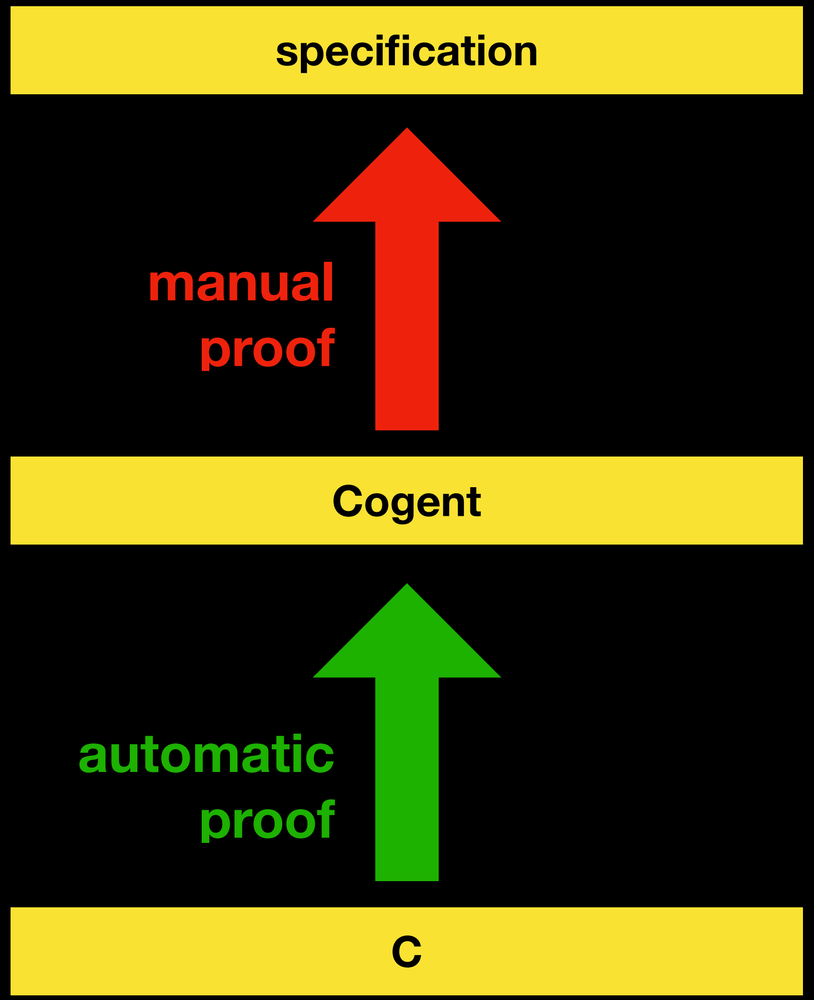

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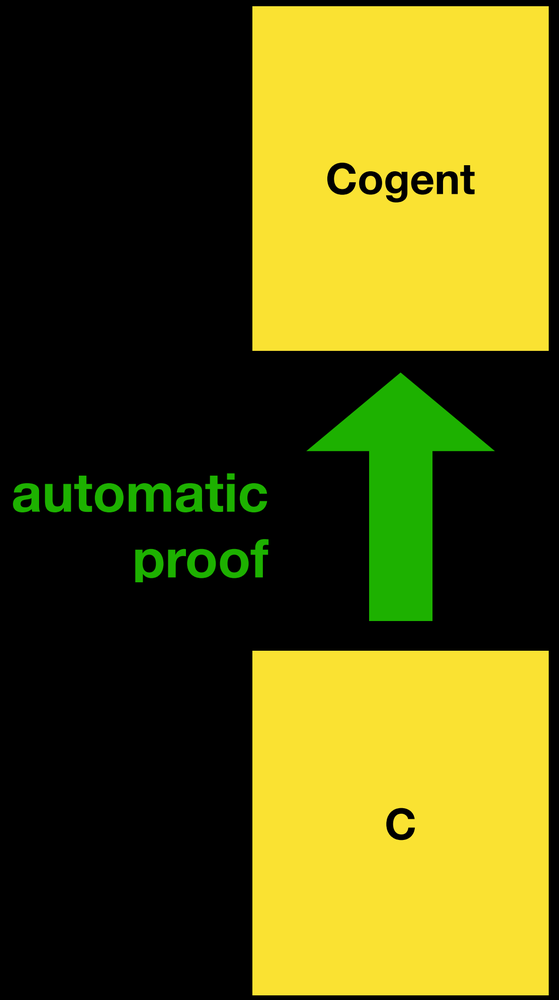

verified

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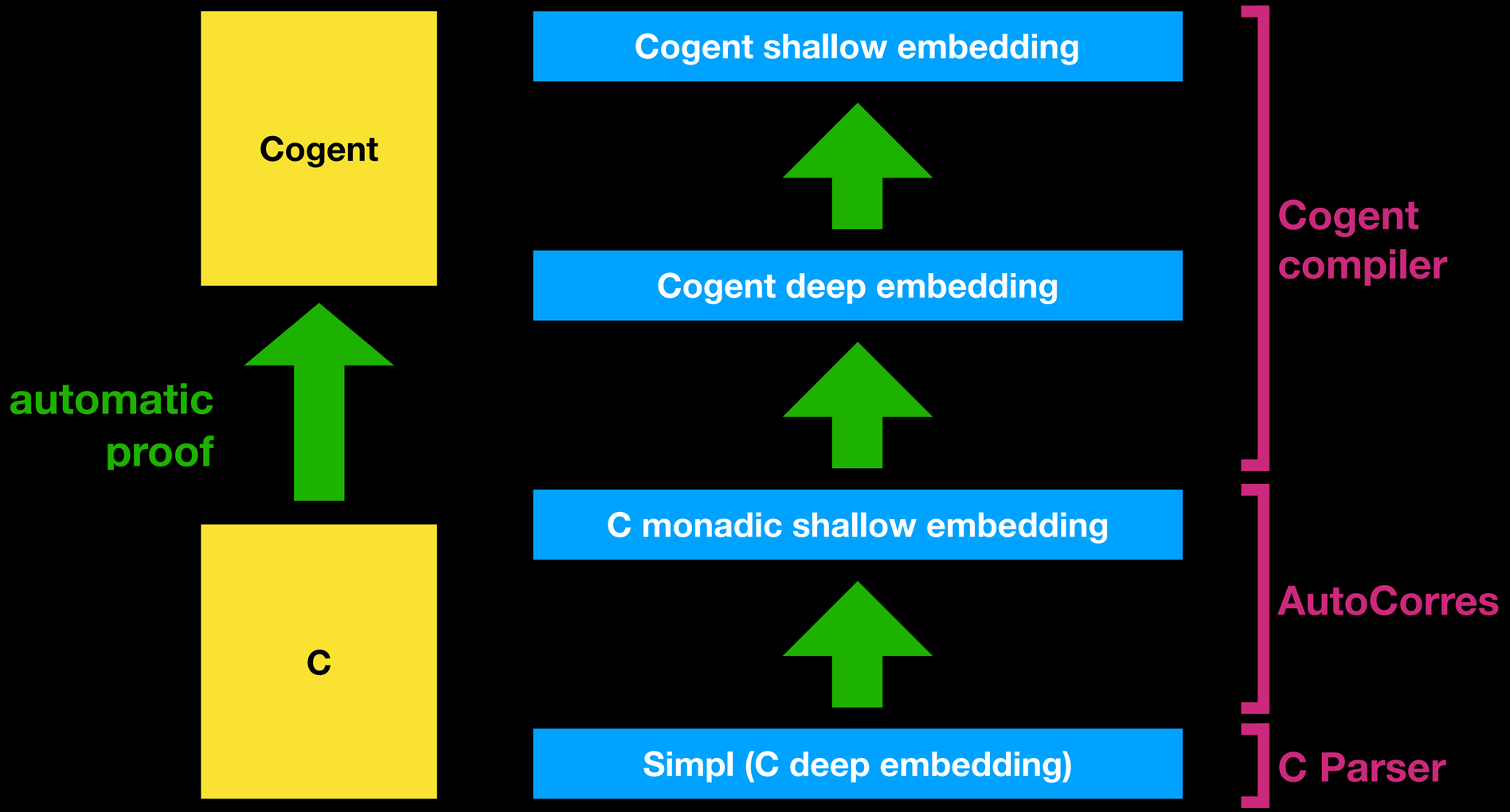

verified

- purely functional
- uniqueness types
- type safe (implies memory safe)

Cogent is a programming language and certifying compiler for building verified low-level systems

low-level systems

- C Foreign Function Interface
- no garbage collection
- destructive updates

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for building verified low-level systems

primitive types

```
 U8 typedef unsigned char        u8;
U16 typedef unsigned short      u16;
U32 typedef unsigned int        u32;
U64 typedef unsigned long long u64;
 () typedef struct unit_t { int   dummy; } unit_t;
Bool typedef struct bool_t { u8  boolean; } bool_t;
```

record types

```
#{f1: U32, f2: Bool} typedef struct t1 {
                        u32 f1;
                        bool_t f2;
                     } t1;

{f1: U32, f2: Bool} typedef struct t1 * t2;
```

variant types

```
<Success U32|Failure ()> enum tag_t {
                             TAG_ENUM_Success,
                             TAG_ENUM_Failure
                         };

                         typedef struct t3 {
                             tag_t tag;
                             u32 Success;
                             unit_t Failure;
                         } t3;
```

C foreign function interface

	efficient	minimises C boilerplate	integrates with existing C code
cogent types only	✔	✔	✗
abstract types			

abstract types

abstract types

list.cogent

```
type ListNode a


type List' a
```

list.ah

```
typedef struct $id:(ListNode a) {
    struct $id:(ListNode a) * next;
    $ty:a val;
} $id:(ListNode a);

typedef struct $id:(List' a) {
    $ty:a head;
} $id:(List' a);
```

abstract types

list.cogent

```
listnode_get: all(a). (ListNode a)! -> a
```

list.ac

```
$ty:a $id:listnode_get($ty:((ListNode a)!) node) {
  return node->val;
}
```

abstract types

C foreign function interface

	efficient	minimises C boilerplate	integrates with existing C code
cogent types only	✔	✔	✗
abstract types	✔	✗	●
conversion by copy	✗	✗	✔
conversion by cast	✔	✔	✔

binary data

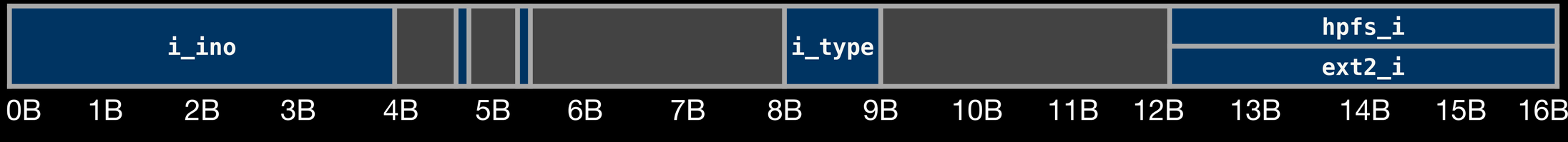
- bit masks and bitwise operations
- **memory layout aware types**

Dargent

attach memory layouts to Cogent types

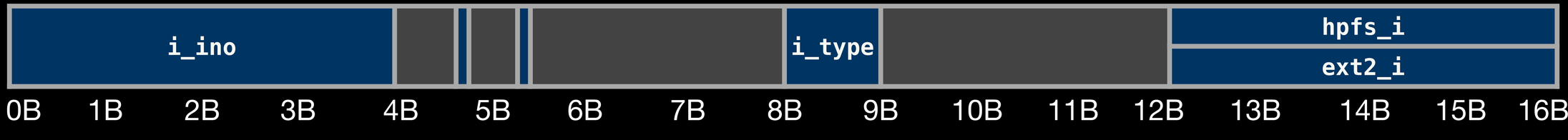
```c
struct inode {
  unsigned int i_ino;
  unsigned int i_state;
  unsigned char i_type;
  union {
    struct hpfs_inode_info hpfs_i;
    struct ext2_inode_info ext2_i;
  } u;
};

// i_state bitmap masks
#define I_FREEING  (1<<5)
#define I_LINKABLE (1<<10)

// i_type enum values
#define I_HPFS_TYPE 0
#define I_EXT2_TYPE 1
```

```
type Inode =
  { i_ino:      U32
  , i_freeing:  Bool
  , i_linkable: Bool
  , u:
    < Ext2I Ext2InodeInfo
    | HpfsI HpfsInodeInfo
    >
  } with layout
  { i_ino:      4B
  , i_freeing:  1b at 4B+5b
  , i_linkable: 1b at 4B+10b
  , u:          1B at 8B
    | 0 -> Ext2I Ext2InodeL at 12B
    | 1 -> HpfsI HpfsInodeL at 12B
  }
```



```
type Inode =
  { i_ino:       U32
  , i_freeing:   Bool
  , i_linkable: Bool
  , u:
    < Ext2I Ext2InodeInfo
    | HpfsI HpfsInodeInfo
    >
  } with layout
  { i_ino:       4B
  , i_freeing:   1b at 4B+5b
  , i_linkable: 1b at 4B+10b
  , u:           1B at 8B
    | 0 -> Ext2I Ext2InodeL at 12B
    | 1 -> HpfsI HpfsInodeL at 12B
  }
```

```
typedef struct t1 {
  unsigned int data[4U];
} *t1;
```



```c
typedef struct t1 {
  unsigned int data[4U];
} *t1;
```

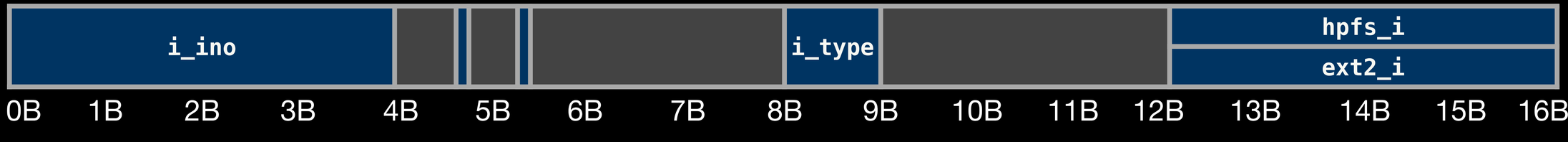
```c
static inline unsigned int
d4_get_i_linkable_part0(t1 b) {
  return b->data[1U] >> 10U & 1U;
}

static inline bool_t
d3_get_i_linkable(t1 b) {
  return (bool_t) {
    .boolean = (unsigned char)
d4_get_i_linkable_part0(b) << 0U
  };
}
```

```c
typedef struct t1 {
  unsigned int data[4U];
} *t1;
```

```c
static inline void
d6_set_i_linkable_part0(
    t1 b, unsigned int v) {
  b->data[1U]
    = (b->data[1U] & ~(1U << 10U))
    | (1U & v) << 10U;
}

static inline void
d5_set_i_linkable(t1 b, bool_t v){
  d6_set_i_linkable_part0(b,
    (unsigned int)
    (v.boolean >> 0U));
}
```

```
link: (Inode, Bool) -> Inode
link (inode {i_linkable=old}, new)
  = inode {i_linkable=new}
```

```
typedef struct t2 {
  t1      p1;
  bool_t p2;
} t2;

static inline t1 link(t2 a1) {
  t1 r2 = a1.p1;
  bool_t r3 = a1.p2;
  bool_t r4 =
      d3_get_i_linkable(r2);
  t1 r5 = r2;
  d5_set_i_linkable(r5, r3);
  t1 r6 = r5;
  return r6;
}
```



Dargent

- layouts only affect types
- conversion by cast
- native bitmaps

plan

- ☑ initial language design
- ☑ compiler data structures
- ☑ code generation
- ☑ parser, type checker and desugarer
- ☐ verification

verification

- update refinement proofs
- relation between getters/setters and layouts

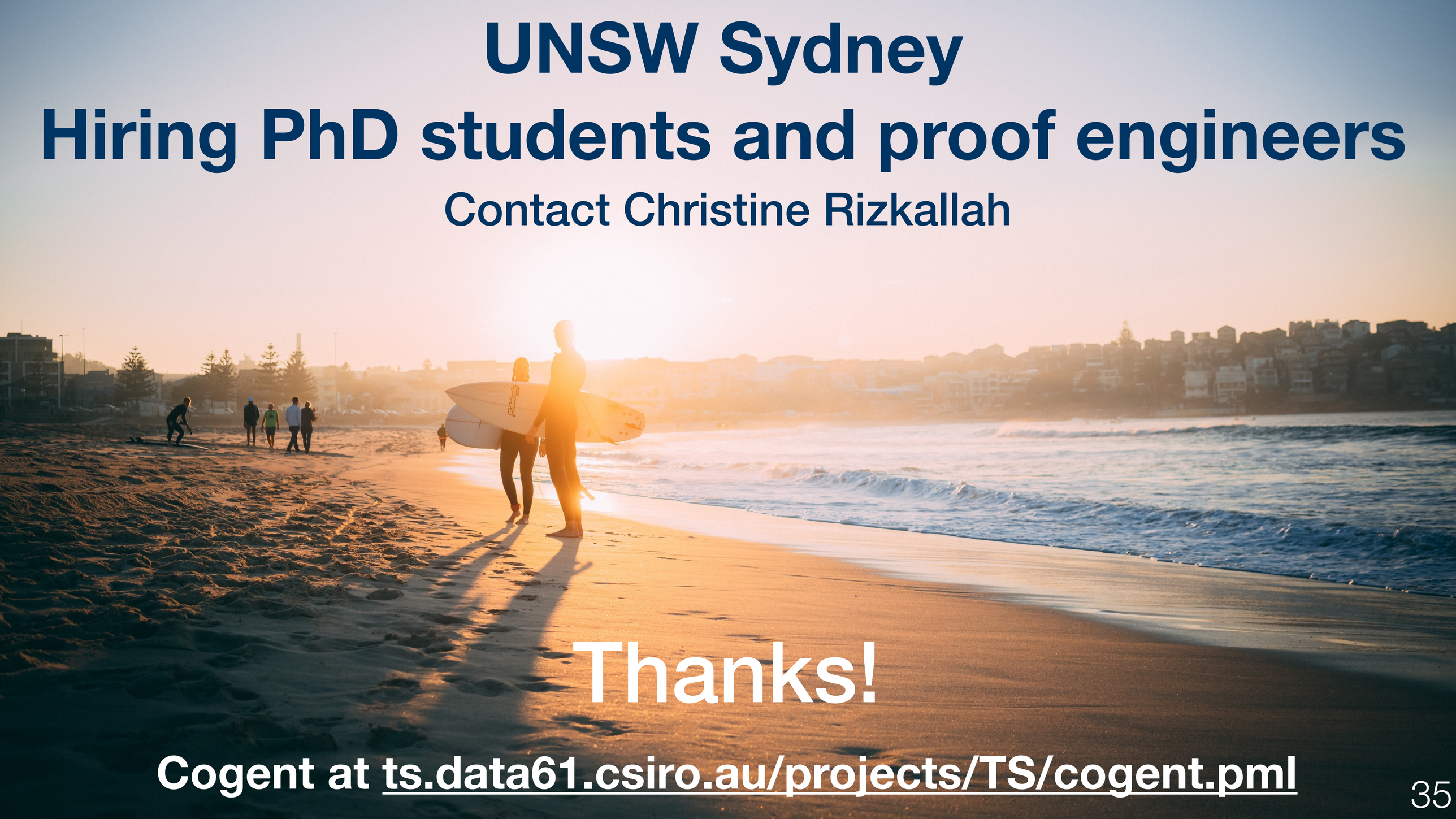
future work

- layout polymorphism and inference
- endianness
- nested pattern matching

Sydney

UNSW Sydney
Hiring PhD students and proof engineers

Contact Christine Rizkallah



Thanks!

Cogent at ts.data61.csiro.au/projects/TS/cogent.pml