A Formalization of the C99 Standard in HOL, Isabelle and Coq

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The C99 standard

The official description issued by ANSI and ISO:

- Written in English
- No mathematically precise formalism
- Incomplete and ambiguous

The Formalin project

- May 2011 to May 2015
- `http://ch2o.cs.ru.nl/`
- Create a formalization of the **complete** C99 standard
- In the theorem provers HOL4, Isabelle/HOL and Coq
- Which follow the standard closely
- All derived from a common master formalization (e.g. in Ott)

Features

- C preprocessor
- C standard library
- Floating point arithmetic
- Casts
- Non-determinism
- Sequence points
- Alignment requirements
- Non-local control flow (`goto`, `setjmp`/`longjmp`, signal handling)
- `volatile`, `restrict` and `const` variables
- Programs in a 'freestanding environment'

Purposes

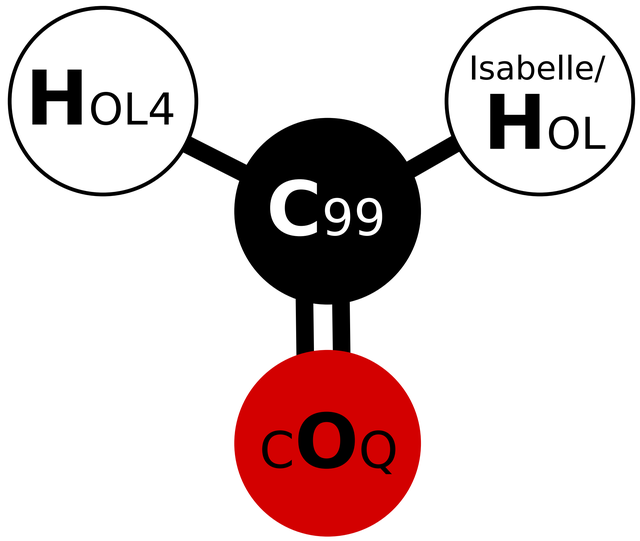
- Utterly precise version of the standard. Useful for compiler writers and programmers
- Validate correctness of formal versions of subsets of C (e.g. Compcert) with respect to the whole standard
- Verify correctness of verification conditions generated by tools (e.g. VCC or Frama-C)

Related projects

- Michael Norrish. C and C++ semantics (L4.verified)
- Xavier Leroy *et al.* Verified C compiler in Coq (Compcert)
- Chucky Ellison and Grigore Rosu. Executable C semantics in Maude

The formalizations

- Describe a space `C_semantics` of all possible C semantics with relations between these semantics
- And, a small step semantics, `C99 : C_semantics`



Dissemination

- Open source, under a BSD-style license
- Using MKM tools like those being developed in the MathWiki project

Some subtleties of C

- Undefined behavior due to unknown evaluation order:

```
int i = 0;
i = ++i; // undefined
```

- Overflow of signed integers is undefined:

```
int i = INT_MAX;
return i < i + 1;
// undefined: hence, a compiler is allowed to
// optimize this to return 1
```

  On the other hand, unsigned integer arithmetic is modular
- Undefined behavior due to jumping into a block with a variable length array declaration:

```
goto foo; // undefined
int a[n];
label foo; printf("bar\n");
```

- Freeing memory makes pointers to it indeterminate

```
int *x = malloc(sizeof(int));
free(x);
printf("%p\n", x); // undefined
```

- Contiguously allocated objects

```
int x = 30, y = 31;
int *p = &x + 1, *q = &y;
if (memcmp(&p, &q, sizeof(p)) == 0) {
  printf("%d\n", *p);
  // the standard is unclear whether this is
  // defined (see Defect report #260).
}
```

References

- International Organization for Standardization. *ISO/IEC 9899:1999: Programming languages – C*. ISO Working Group 14, 1999.
- Freek Wiedijk. *Formalizing the C99 standard in HOL, Isabelle and Coq*. `http://www.cs.ru.nl/~freek/notes/ch2o.pdf`, 2010.

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