# Ultimate Kojak

ultimate.informatik.uni-freiburg.de

github.com/ultimate-pa/ultimate

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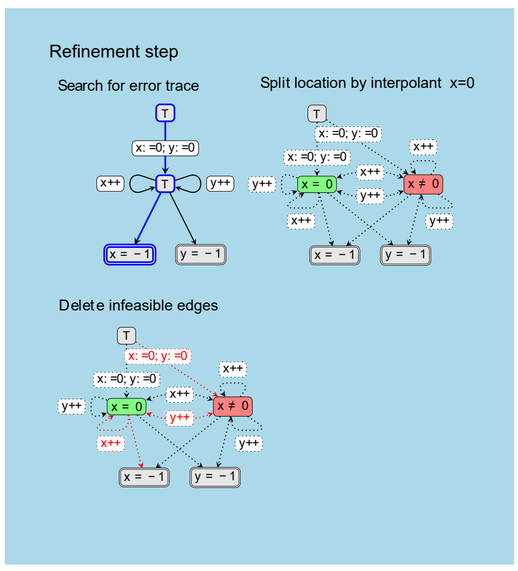
## Features

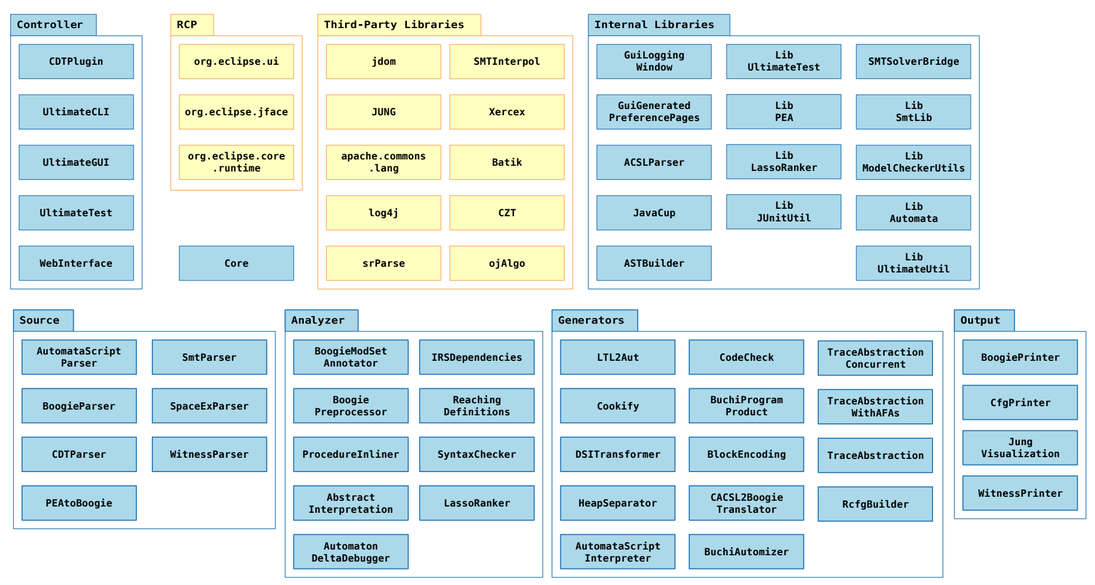
- Reachability analysis
- Memory safety analysis
- Bitprecise analysis
- IEEE 754 floating point analysis
- Error witnesses
- Correctness witnesses

## Techniques

- Abstraction refinement
- Configurable block encodings
- Multi SMT solver support
- Newton-style interpolation



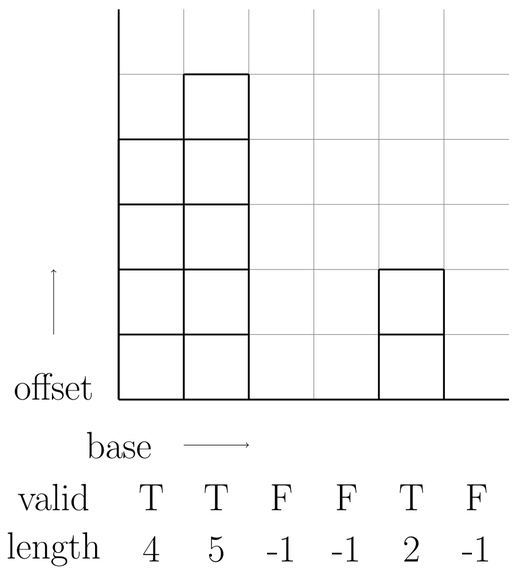

## Ultimate program analysis framework




## C memory model

Models dynamically allocated memory through Boogie arrays:

- `memory-[int|pointer|bitvector8|...]`: store memory contents
  - one array per used Boogie data type
  - two dimensional, a memory address has components "base" and "offset"
  - models disjointness of memory areas allocated by different malloc calls
- `valid`: store which base addresses are allocated
- `length`: store maximal offset at each base address
- "`*p` is a valid pointer dereference" $\iff$ `valid`[`p.base`] $\wedge$ `p.offset` $\leq$ `length`[`p.base`]
- "Program has no memory leaks" $\iff$ `valid` $=$ `old(valid)` at the end of `main`




## SMT solver integration

### Hoare triple checks

"Is $\{P\}\, s\, \{Q\}$ a Hoare triple?"

Features:

- Simplify check if $(variables(P) \cup variables(st)) \cap variables(Q) = \emptyset$.
  - often blocked because $P$, $st$ and $Q$ access the same array (but perhaps at different positions)
  - attempt to partition arrays via "alias analysis" (work in progress)
- Avoid checks with intricate predicates.
- Use incremental (push/pop) solver queries when possible, e.g., group checks that share the same precondition $P$.
- Abstract interpretation-based:
  Check if $post^{\#}(P^{\#}, st) \sqsubseteq Q^{\#}$ holds in some abstract domain.
- Unify equivalent predicates.
- Cache Hoare triples and implication between predicates.

### Tree interpolation

- Interpolating solvers used by Ultimate: SMTInterpol, Z3
- Tree interpolation syntax example (procedures `foo`, `bar`):

```
(assert (! (..) :named foo-stm1))
(assert (! (..) :named foo-stm2))
(assert (! (..) :named bar-stm1))
(assert (! (..) :named bar-stm2))
(assert (! (..) :named foo-stm3))
(check-sat)
(get-interpolants (foo-stm1 foo-stm2 (bar-stm1 bar-stm2) foo-stm3))
```

### Interface

- Java interface (currently only SMTInterpol)
- SMTLib2 interface
- Solvers in use at SV-COMP 2018: SMTInterpol, Z3, MathSat, CVC4
  as many as we can get!

## Newton-style interpolation

- Input: infeasible trace $st_1, \ldots, st_n$, unsatisfiable core UC $\subseteq \{st_1, \ldots, st_n\}$
- Replace statements not in UC:
  assume statement `ψ` $\rightsquigarrow$ `skip`
  assignment statement `x:=t` $\rightsquigarrow$ `havoc x`
- Compute sequence of predicates $\varphi_0, \ldots, \varphi_n$ iteratively using strongest post operator *post*

$$\varphi_0 := true$$
$$\varphi_{i+1} := post(\varphi_i, st_{i+1})$$

- Eliminate each variable from predicate $\varphi_i$ that is not live at position i of the trace.
- Output: sequence of predicates $\varphi_0, \ldots, \varphi_n$ which is a sequence of interpolants for the infeasible trace $st_1, \ldots, st_n$

| trace $\tau$ | state assertions for $\tau$ | interpolating trace $\tau^{\#}$ | state assertions for $\tau^{\#}$ |
|---|---|---|---|
| | $\varphi_0$ $true$ | | $\varphi_0$ $true$ |
| $st_1$ `b:=a` | | `b:=a` | |
| | $\varphi_1$ $a = b$ | | $\varphi_1$ $a = b$ |
| $st_2$ `x:=0` | | `havoc x` | |
| | $\varphi_2$ $a = b \wedge x = 0$ | | $\varphi_2$ $a = b$ |
| $st_3$ `havoc p` | | `havoc p` | |
| | $\varphi_3$ $a = b \wedge x = 0$ | | $\varphi_3$ $a = b$ |
| $st_4$ `!a[p]` | | `!a[p]` | |
| | $\varphi_4$ $a = b \wedge x = 0 \wedge a[p] = false$ | | $\varphi_4$ $a = b \wedge a[p] = false$ |
| $st_5$ `a[p]:=true` | | `a[p]:=true` | |
| | $\varphi_5$ $a = b[p := true] \wedge x = 0 \wedge a[p] = true$ | | $\varphi_5$ $a = b[p := true] \wedge a[p] = true$ |
| $st_6$ `x:=x+1` | | `havoc x` | |
| | $\varphi_6$ $a = b[p := true] \wedge x = 1 \wedge a[p] = true$ | | $\varphi_6$ $a = b[p := true] \wedge a[p] = true$ |
| $st_7$ `a[p]:=false` | | `a[p]:=false` | |
| | $\varphi_7$ $a = b \wedge x = 1 \wedge a[p] = false$ | | $\varphi_7$ $a = b \wedge a[p] = false$ |
| $st_8$ `a!=b` | | `a!=b` | |
| | $\varphi_8$ $false$ | | $\varphi_8$ $false$ |