CRAVE 2.0: The Next Generation Constrained Random Stimuli Generator for SystemC

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Agenda

- Motivation
- Basics of CRAVE
- Major new features in CRAVE 2.0
  - Soft Constraints
  - Distribution Constraints
  - Constraint Partitioning
- Wrap-up

Motivation

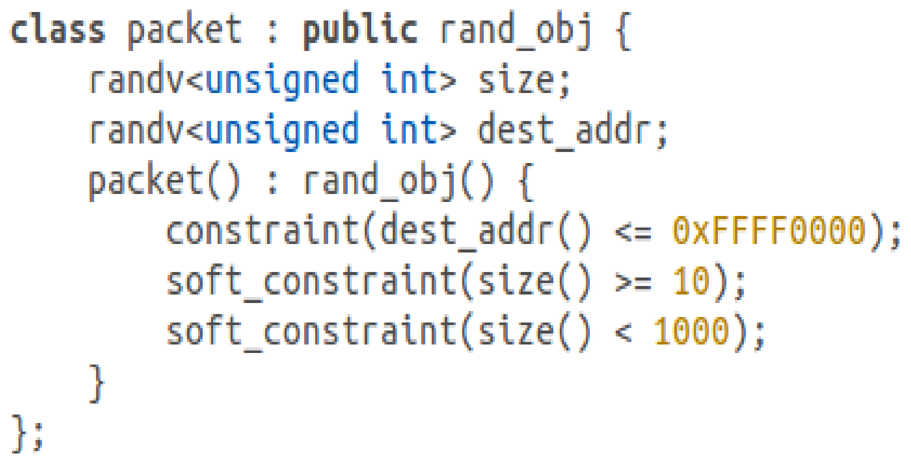
- SystemC
  - IEEE 1666-2011
  - C++ modeling @ multiple levels of abstraction
  - Accellera open-source reference simulator
- Verification of SystemC models
  - In a SystemC-centric design and verification flow
  - Constrained Random Verification (CRV): Accellera open-source SystemC Verification Library (SCV)
  - Lacking in capabilities versus SystemVerilog
    - Limited expressive power
    - Outdated non-scalable constraint solving technology

Our Vision

- Open-source free EDA software
- Powerful & extensible constrained random stimuli generator for SystemC
  - Leverage latest constraint solving technologies
  - Available at github: https://github.com/agra-uni-bremen/crave-bundle
  - Easy integration in a SystemC verification environment
    - DVCon'12: System Verification Methodology (SVM)
    - DVCon'14: Universal Verification Methodology using SystemC (UVM-SystemC)
    - Yours?

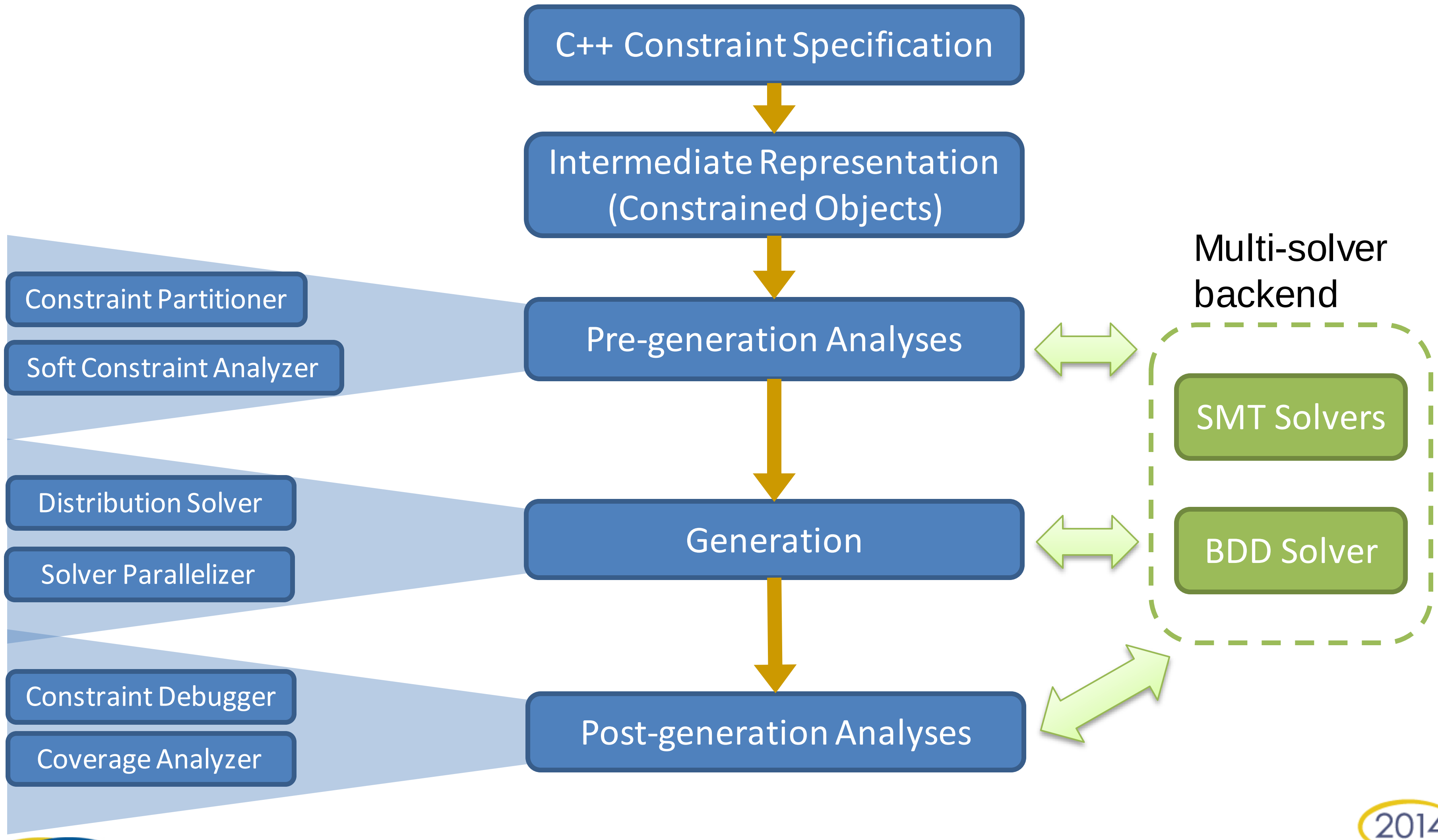
Basics of CRAVE

- **C**onstrained **Ra**ndom **V**erification **E**nvironment
- SystemVerilog-inspired syntax
- Random objects
- Random variables
- Hard/soft constraints



```
class packet : public rand_obj {
    randv<unsigned int> size;
    randv<unsigned int> dest_addr;
    packet() : rand_obj() {
        constraint(dest_addr() <= 0xFFFF0000);
        soft_constraint(size() >= 10);
        soft_constraint(size() < 1000);
    }
};
```

CRAVE Architecture



CRAVE 2.0

- Efficient shaping of the solution space
  - Soft constraints (new feature in SystemVerilog-2012)
  - Distribution constraints
- Faster generation
  - Constraint Partitioning

Soft Constraint

- Hard constraint must always be satisfied!
- Soft constraint shall be satisfied unless contradicted by
  - A hard constraint
  - A soft constraint with **higher priority**
- Typical use case: specify default values, modify later in subsequent specialization.
- In example, size() >= 10 should be overridden by size() >= 5

```
class packet : public rand_obj {
    randv<unsigned int> size;
    randv<unsigned int> dest_addr;
    packet() : rand_obj() {
        constraint(dest_addr() <= 0xFFFF0000);
        soft_constraint(size() >= 10);
        soft_constraint(size() < 1000);
    }
};
```

```
class short_packet : public packet {
    short_packet() : packet() {
        soft_constraint(size() >= 5);
        soft_constraint(size() < 10);
    }
};
```

Soft Constraint

- CRAVE priority scheme
  - Based on creation time of constraint
    - Created later → Higher priority
  - Compactible with SystemVerilog semantics
- But doesn't SCV support soft constraints already (SCV_SOFT_CONSTRAINT)?
  - No priority scheme
  - Drop all soft constraints if contradicted!

```
class packet : public rand_obj {
    randv<unsigned int> size;
    randv<unsigned int> dest_addr;
    packet() : rand_obj() {
        constraint(dest_addr() <= 0xFFFF0000);
        soft_constraint(size() >= 10);
        soft_constraint(size() < 1000);
    }
};
```

```
class short_packet : public packet {
    short_packet() : packet() {
        soft_constraint(size() >= 5);
        soft_constraint(size() < 10);
    }
};
```

Distribution Constraint

- Uniform distribution is not always wanted!
  - a < 10 or b < 10 will be extremely rare → hard to reach coverage closure
- Distribution constraints: user-defined biases to create interesting stimuli (corner cases)

```
class my_rand_obj: public rand_obj {
    randv<unsigned int> a, b, c;
    my_rand_obj() : rand_obj() {
        constraint(if_then(a() < 10, c() == 0));
        constraint(if_then(b() < 10, c() == 1));
        constraint(a() <= 10000000000);
        constraint(b() <= 10000000000);
        constraint(c() <= 10000000000);
    }
};
```

```
class my_rand_obj_ext: public my_rand_obj {
    my_rand_obj_ext() : my_rand_obj() {
        constraint(dist(a(),
            distribution<unsigned int>::create
                (weighted_range<unsigned int>(0, 9, 30)) // 30%
                (weighted_range<unsigned int>(10, 1000000000, 70)) // 70%
        ));
        constraint(dist(b(),
            distribution<unsigned int>::create
                (weighted_range<unsigned int>(0, 9, 50)) // 50%
                (weighted_range<unsigned int>(10, 1000000000, 50)) // 50%
        ));
    }
};
```

Distribution Constraint

- Generated values always in specified ranges (hard constraint)
- Distribution is best-effort but cannot be guaranteed (impossible in many cases)
- Solving algorithm
  - Generate values based on specified distributions
  - Try to solve the constraints with these generated values
  - Drop one randomly chosen value and repeat last step

Distribution Constraint

- But doesn’t SCV also support distributions?
  - They cannot be mixed with other constraints!
  - False report of unsolvable constraints
- CRAVE result

	0	1	2	3	4	5	6	7	8	9	Total	%
a	230	200	230	234	216	214	228	220	219	229	2220	22,2
b	437	420	446	451	408	406	421	413	410	413	4225	42,3

Constraint Partitioning

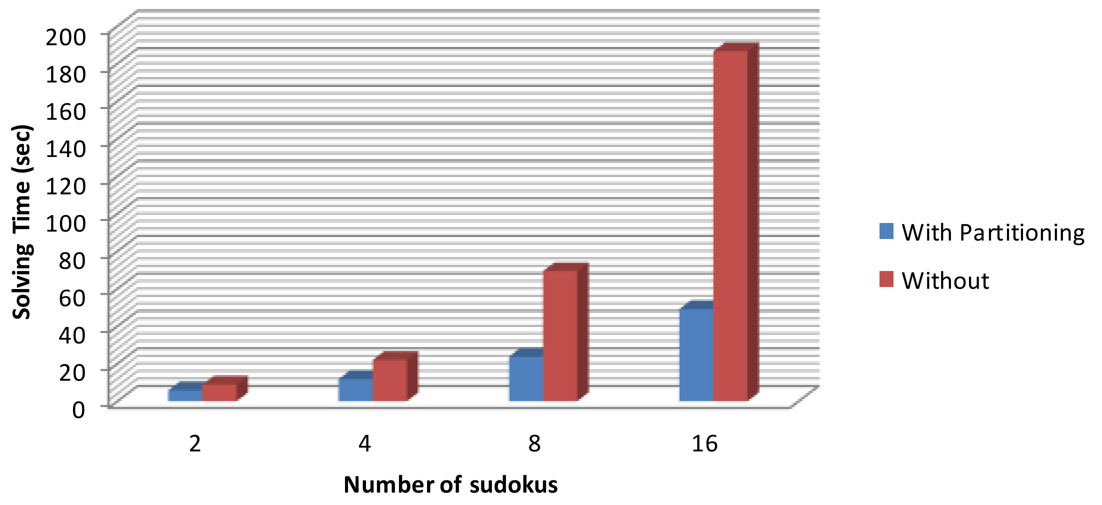
- Observation: multiple disjoint constraint sets in a big set of constraints
- Performance gain by solving disjoint constraint sets independently
- Very efficient implementation possible (e.g. with union-find data structure)

```
class packet : public rand_obj {
    randv<unsigned int> size;
    randv<unsigned int> dest_addr;
    packet() : rand_obj() {
        constraint(dest_addr() <= 0xFFFF0000);
        soft_constraint(size() >= 10);
        soft_constraint(size() < 1000);
    }
};
```

```
class multicast_packet : public packet {
    randv<unsigned int> other_dest_addr[16];
    multicast_packet() : packet() {
        for (int i = 0; i < 16; i++)
            constraint(other_dest_addr[i]() <= 0xFFFF0000);
    }
};
```

Constraint Partitioning – Experiments

- Multicast packet
  - SCV (no CP available) timeouts
  - CRAVE (both with and without CP) returns instantly
- Sudoku puzzle



Wrap-up

- CRAVE 2.0
  - Open-source constrained random stimuli generator for SystemC/C++
  - Powerful constraint solving technologies
  - Extensible architecture
  - Frequently added new features, recently: soft constraints, distribution constraints, constraint partitioning
- What‘s next?
  - Integration of coverage models
  - Graph-based specification

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Thanks for your time!
Questions?