rTRNG: Advanced Parallel Random Number Generation in R

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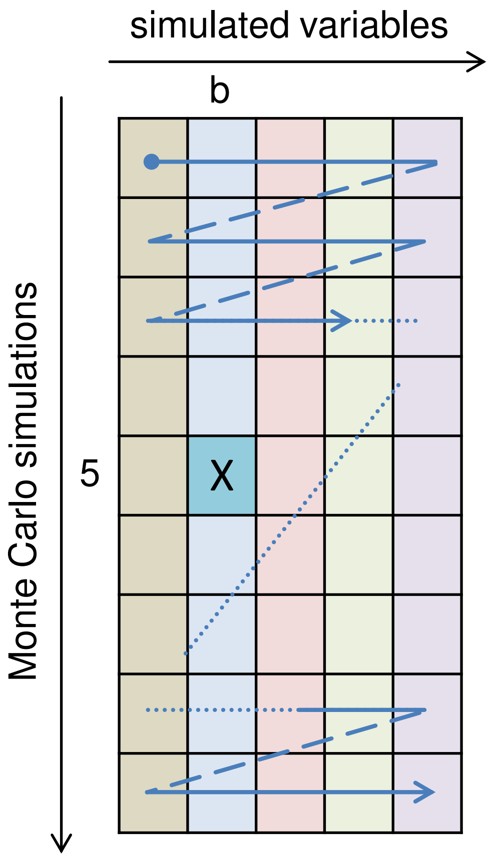
useR!2017 – Brussels

Introduction and Motivation



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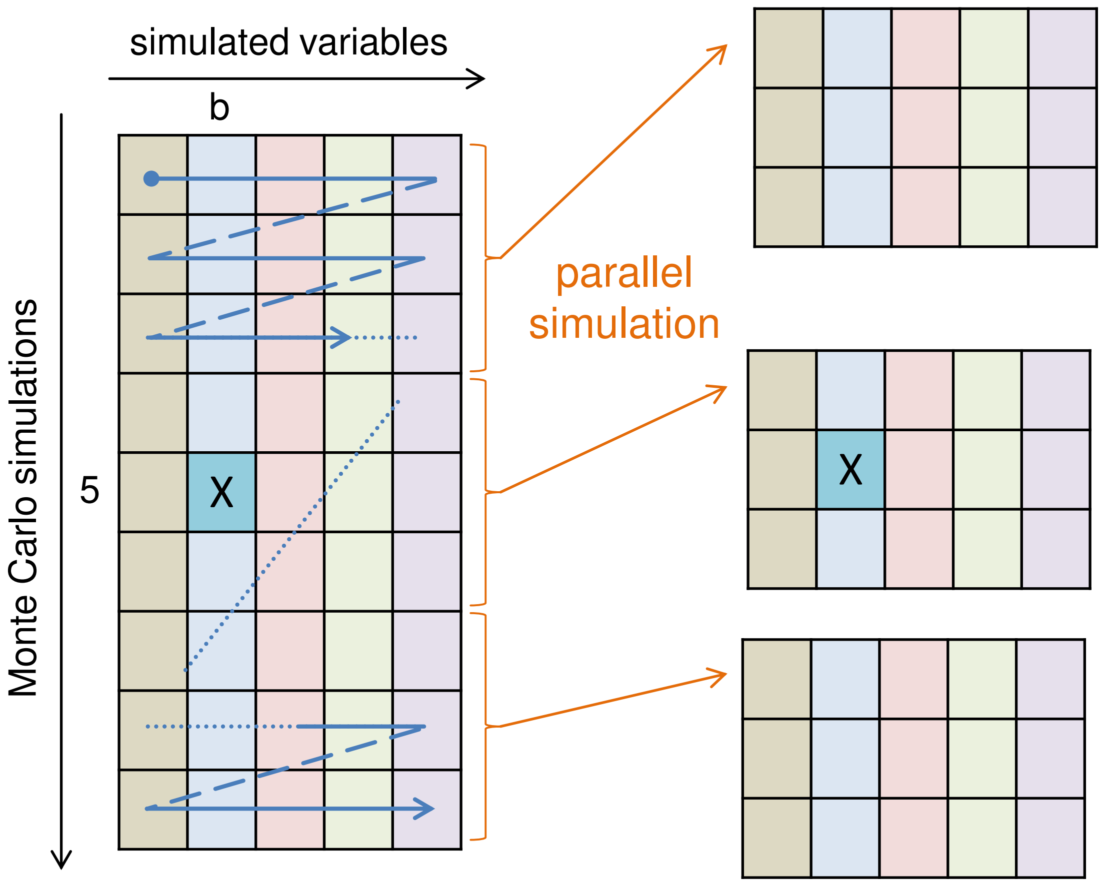

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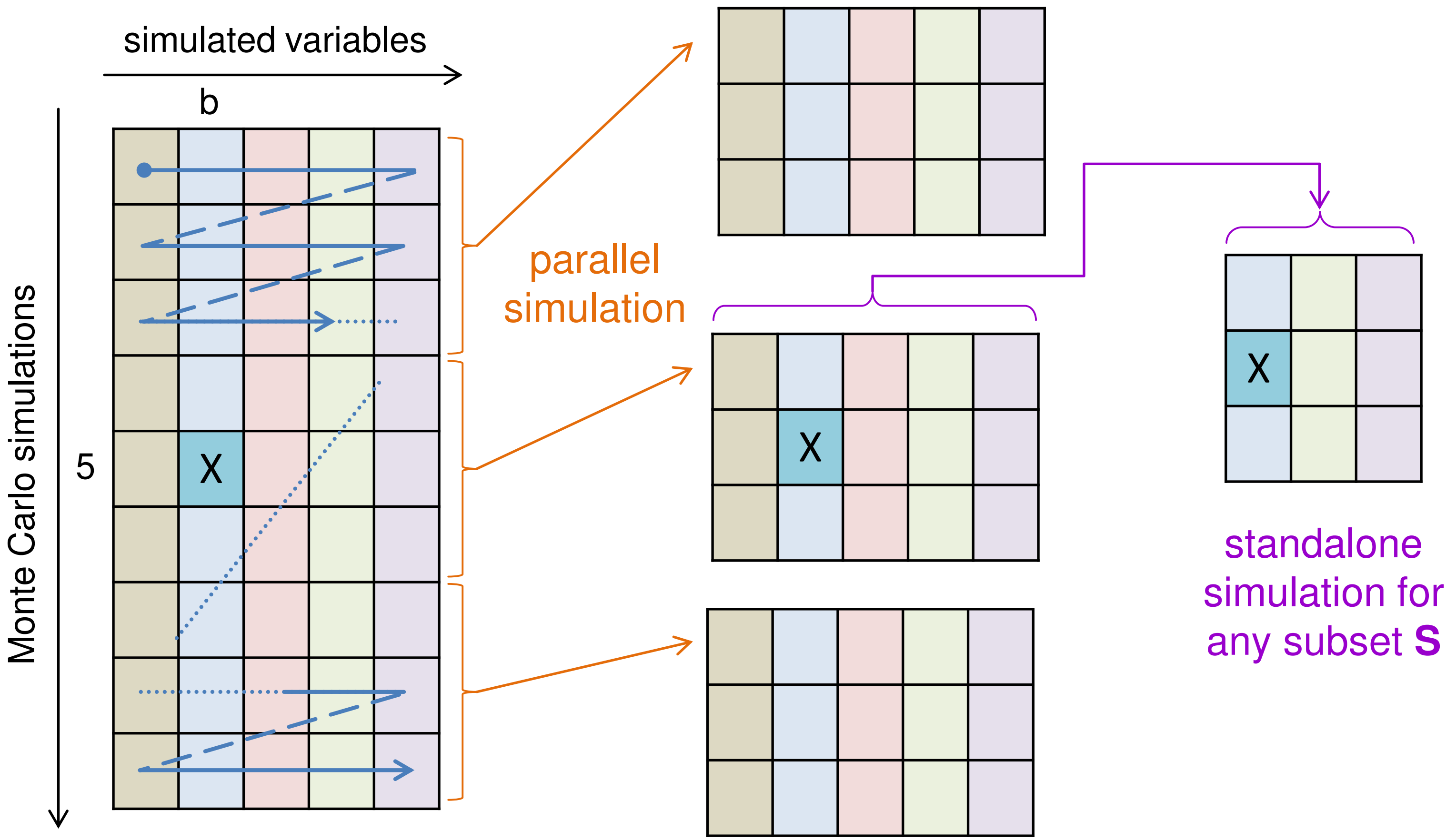
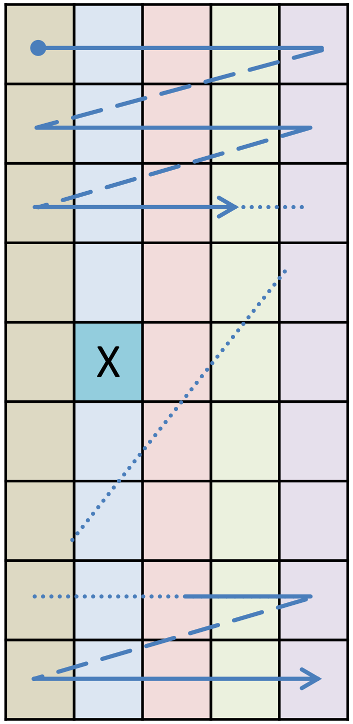


Consistency with **full sequential simulation**:
simulating only **S**, how can we keep X same as the original **{5,b}**?

Introduction and Motivation

Limitation: conventional (Pseudo)RNGs based on deterministic recurrence are intrinsically sequential $r_i = f(r_{i-1}, r_{i-2}, \ldots, r_{i-k})$



- Key principles with parallel RNG
  - independent, non-overlapping streams
  - *fair-playing* – results independent of architecture, parallelization techniques, number of parallel processes

  => no random seeding and individual RNGs per process
- Avoid inefficient *naïve* approaches
  - simulate full sequence and discard draws
  - storing relevant seeds
- Available approaches in R
  - `parallel`, `rstream`, `rlecuyer`
  - focus on independent sub-streams

[S. Mertens, Random Number Generators: A Survival Guide for Large Scale Simulations, http://arxiv.org/abs/0905.4238]

rTRNG: Advanced Parallel RNG in R

```
devtools::install_github("miraisolutions/rTRNG", build_vignettes = TRUE)
```

Based on Tina's Random Number Generator library by Heiko Bauke

"State of the art C++ pseudo-random number generator library for sequential and parallel Monte Carlo simulations"

http://numbercrunch.de/trng
https://github.com/rabauke/trng4

- collection of random number engines (PRNGs) and distributions
  - linear congruential, multiple recurrence, YARN, lagged Fibonacci, Mersenne-Twister
  - uniform, (truncated) normal, (two-sided) exponential, maxwell, cauchy, logistic, lognormal, pareto, power-law, tent, weibull, extreme value, gamma, beta, chi2, student-t, snedecor-F, rayleigh, bernoulli, (negative) binomial, hypergeometric, geometric, poisson, discrete
- compliant with ISO C++ standard for PRNGs and C++ STL

Package rTRNG

- usage of distributions and engines exposed to R
- C++ library and headers available to other R projects using C++

rTRNG: Distributions and Engines

- Drawing from distributions: `r<dist>_trng(..., engine, parallelGrain)`
  - `runif_trng`, `rnorm_trng` (more to come)
- Engines: exposed as Reference Classes via Rcpp Modules
  - Conventional RNGs: `lagfib(2/4)(plus/xor)_19937_64`
    `mt19937(_64)`
  - Parallel RNGs: `lcg64(_shift)`
    `mrg2, mrg3(s), mrg4, mrg5(s)`
    `yarn2, yarn3(s), yarn4, yarn5(s)`

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    - Parallel RNGs: `lcg64(_shift)` `mrg2, mrg3(s), mrg4, mrg5(s)` `yarn2, yarn3(s), yarn4, yarn5(s)`
        - based on linear recurrences (linear feedback shift register)

$$r_i = a_1 r_{i-1} + a_2 r_{i-2} + \ldots + a_n r_{i-n} \bmod m$$

        - strong theoretical foundation about statistical properties (pseudo-noise) and transformations
        - simple mathematical structure => manipulation of RNG streams

Set / Create / Manipulate Engines

Base-R-like usage: select and manipulate a global engine

```
help(TRNG.Random)

    TRNGkind(kind)
    TRNGseed(seed)
    TRNG.Random.seed()
    TRNGjump(steps)
    TRNGsplit(p, s)
```

Used as default `engine` by `r<dist>_trng`

Create and manipulate individual reference engine objects

```
help(TRNG.Engine)
    $new(), $new(seed), $new(string)
    $kind(), $name()
    $seed(seed)
    $.Random.seed()
    $jump(steps)
    $split(p, s)
    $toString()
    $copy()
    $show()
```

Conventional RNG Usage

Base-R-like usage: select and manipulate a global engine

`example(TRNG.Random)`

```
# set a specific TRNG kind
TRNGkind("yarn2")
# seed the current engine
TRNGseed(12358)
# draw 10 random variates
runif_trng(10)

# full engine specification
engspec <- TRNG.Random.seed()
# [...]

# restore the engine
TRNG.Random.seed(engspec)
```

Create and manipulate individual reference engine objects

`example(TRNG.Engine)`

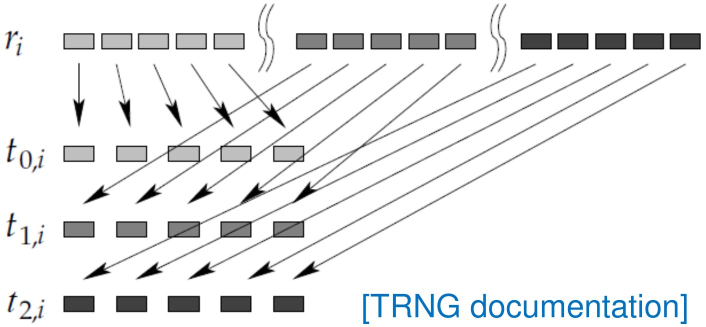
```
# create a reference object
rng <- yarn2$new()
# seed
rng$seed(12358) # yarn2$new(12358)
# draw from distr. using the engine
runif_trng(10, engine = rng)

# engine state representation
state <- rng$toString()
engspec <- rng$.Random.seed()
# [...]
# restore as (global) engine
rng <- yarn2$new(state)
TRNG.Random.seed(engspec)

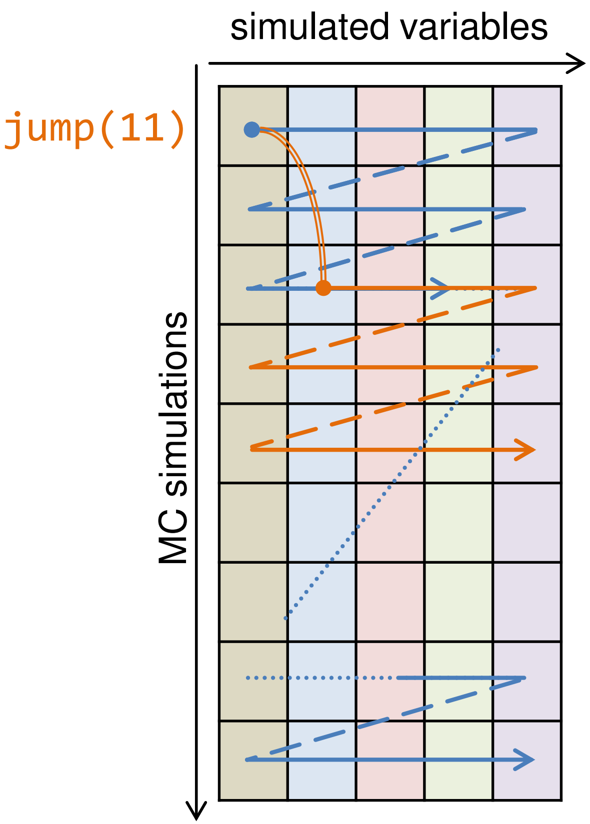
# reference vs. copy
rng_ref <- rng
rng_cpy <- rng$copy()
```

Advanced RNG Manipulation: jump(steps)

- Advance the internal state of the RNG by steps without generating all intermediate states



[TRNG documentation]



- For LFSR sequences, achieved in O(n^3 ln(steps))

$$r_i = a_1 r_{i-1} + a_2 r_{i-2} + \ldots + a_n r_{i-n} \bmod m$$

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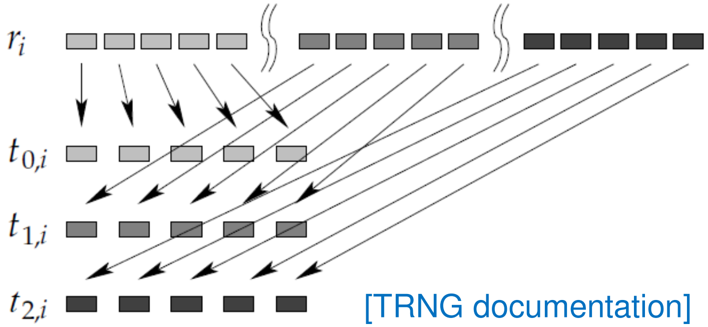
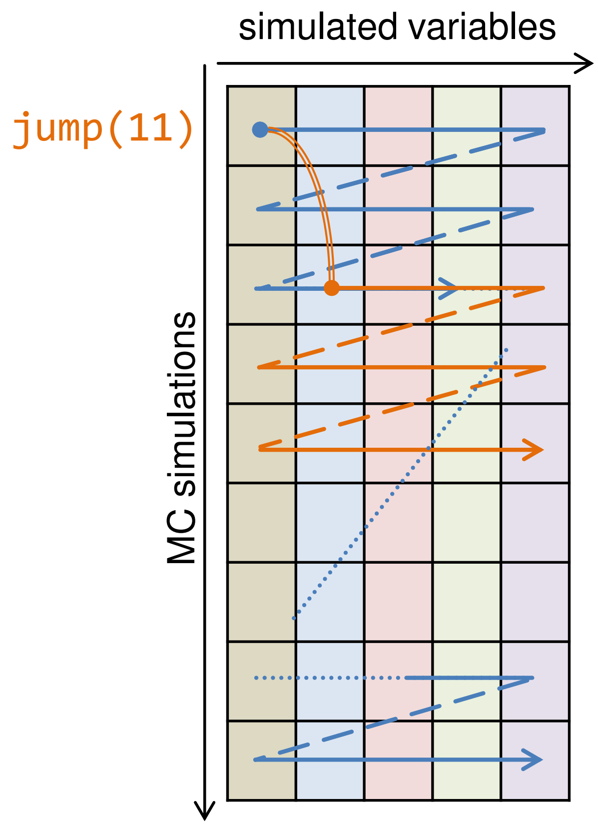


- For LFSR sequences, achieved in O(n^3 ln(steps))

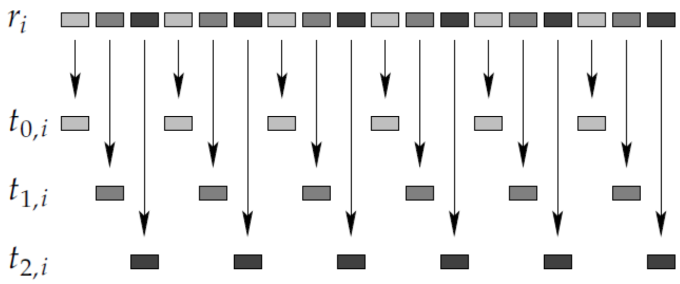
$$r_i = a_1 r_{i-1} + a_2 r_{i-2} + \ldots + a_n r_{i-n} \bmod m$$

```
rng <- yarn2$new(12358)
runif_trng(15, engine = rng)
##  [1] 0.5803 0.3394 0.2214 0.3694 0.5427
##  [6] 0.0029 0.1240 0.3468 0.1218 0.9471
## [11] 0.3365 0.1289 0.3804 0.5507 0.4360
rng$seed(12358)
rng$jump(11); runif_trng(4, engine = rng)
## [1] 0.1289 0.3804 0.5507 0.4360
```

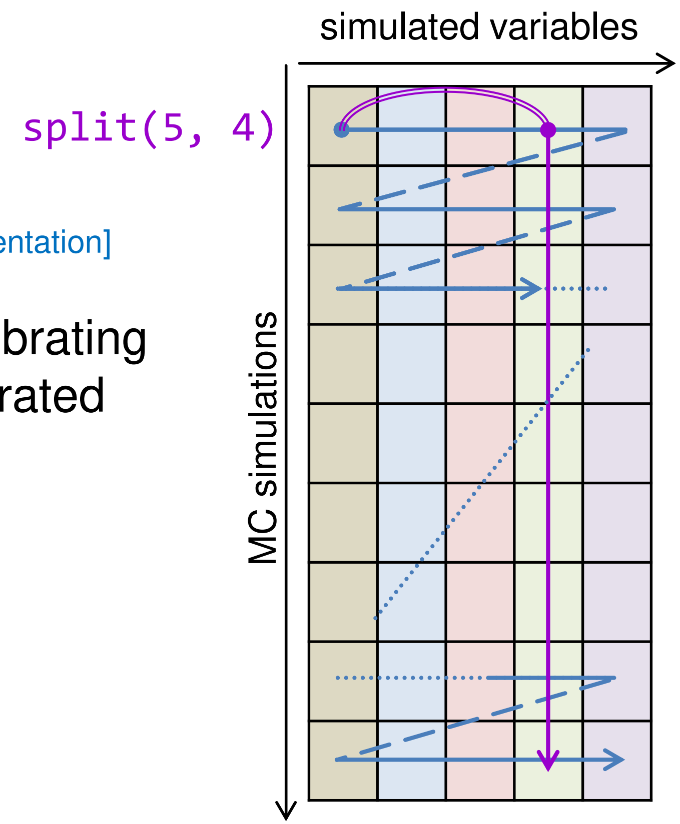


Advanced RNG Manipulation: split(p, s)

- Generate directly the s-th of p decimated subsequences



[TRNG documentation]



- New RNG computed in polynomial time by calibrating the internal parameters => subsequence generated directly (no generation-time complexity)

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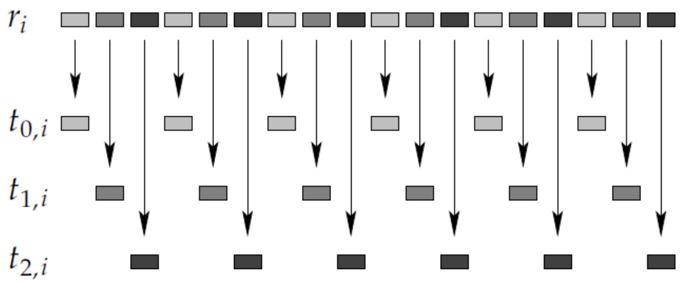

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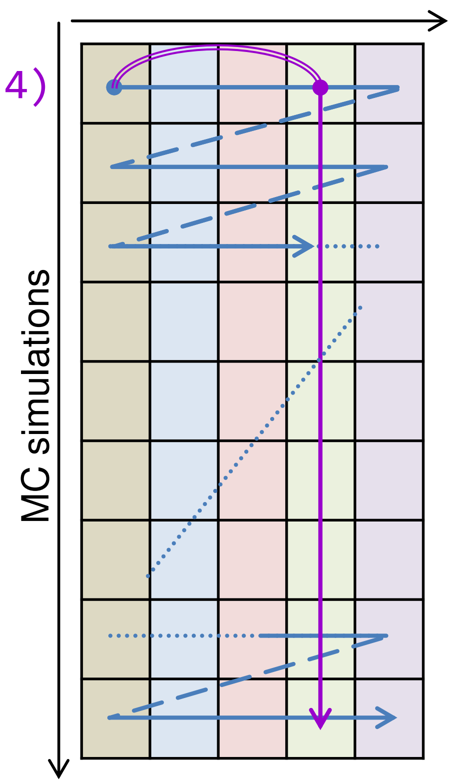

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```
TRNGkind("yarn2"); TRNGseed(12358)
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##  [6] 0.0029 0.1240 0.3468 0.1218 0.9471
## [11] 0.3365 0.1289 0.3804 0.5507 0.4360
TRNGseed(12358)
TRNGsplit(5, 4); runif_trng(3)
## [1] 0.3694 0.1218 0.5507
```

rTRNG: R/C++ Projects

- TRNG C++ library and headers available in C++ code within other R projects
- Full power and flexibility for implementing high-performance parallel simulation / Monte Carlo algorithms

- Standalone C++ "scripts" sourced via `Rcpp::sourceCpp`

```
// [[Rcpp::depends(rTRNG)]]
```

- R packages importing rTRNG

```
DESCRIPTION
  Imports: rTRNG
  LinkingTo: rTRNG
NAMESPACE
  importFrom(rTRNG, TRNG.Version)
Makevars(.win)
  ?rTRNG::LdFlags
```

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```
// [[Rcpp::depends(rTRNG)]]
#include <Rcpp.h>
#include <trng/yarn2.hpp>
#include <trng/uniform_dist.hpp>
using namespace Rcpp;
using namespace trng;
// [[Rcpp::export]]
NumericVector exampleCpp() {
  yarn2 rng(12358);
  rng.jump(15);
  rng.split(5, 3); // 0-based index
  NumericVector x(3);
  uniform_dist<> unif(0, 1);
  for (int i = 0; i < 3; i++) {
    x[i] = unif(rng);
  }
  return x;
}
```

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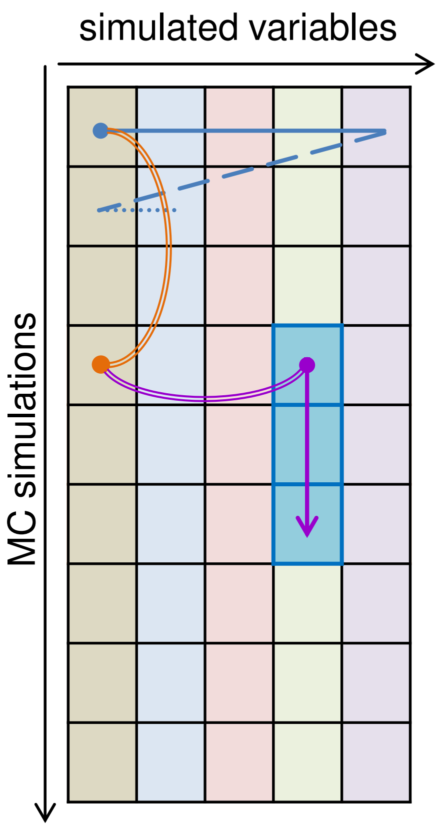
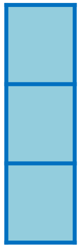


standalone, consistent sub-simulation



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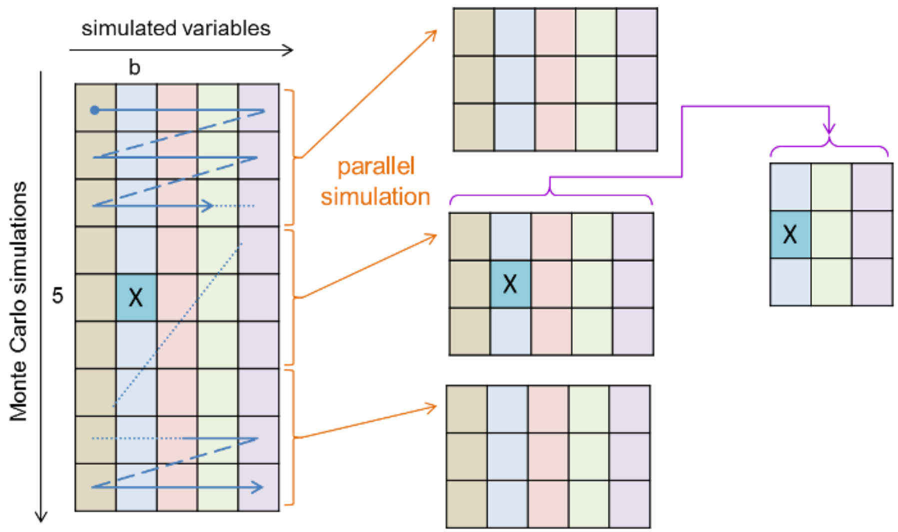
  rng.jump(15);
  rng.split(5, 3); // 0-based index
  NumericVector x(3);
  uniform_dist<> unif(0, 1);
  for (int i = 0; i < 3; i++) {
    x[i] = unif(rng);
  }
  return x;
}
```

Example: Parallel Sub-matrix Simulation

- Monte Carlo simulation of a matrix of i.i.d normal random variables

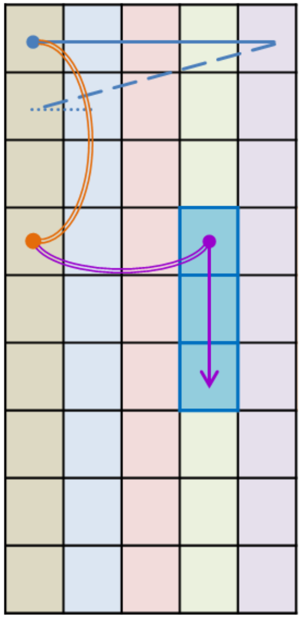


- Consistent (*fair-playing*), parallel simulation of any subset of the variables
  - combine rTRNG with RcppParallel
  - `vignette("mcMat", package = "rTRNG")`

Example: Parallel Sub-matrix Simulation

```
vignette("mcMat", package = "rTRNG")
```

```
struct MCMatWorker : public Worker {
  RMatrix<double> M;
  const RVector<int> subCols;
  // constructor [omitted]
  // operator processing an exclusive range of row indices
  void operator()(std::size_t begin, std::size_t end) {
    trng::yarn2 r(12358), rj;
    trng::normal_dist<> normal(0.0, 1.0);
    r.jump((int)begin*M.ncol());
    for (IntegerVector::const_iterator jSub = subCols.begin();
         jSub < subCols.end(); jSub++) {
      int j = *jSub-1; rj = r; rj.split(M.ncol(), j);
      for (int i = (int)begin; i < (int)end; i++) {
        M(i, j) = normal(rj);
      }
    }
  }
};
```



```
// [[Rcpp::export]]
NumericMatrix mcMatRcppParallel(const int nrow, const int ncol,
                                const IntegerVector subCols) {
  NumericMatrix M(nrow, ncol);
  MCMatWorker w(M, subCols); parallelFor(0, M.nrow(), w);
  return M;
}
```

Take-away

- State-of-the-art parallel RNGs available to the R community
  - Experiment/prototype your parallel algorithm in R
    - Base-R-like behavior
    - Manipulation of random engine objects
  - Full potential by using TRNG library and headers in R/C++ projects and packages
- rTRNG package on our GitHub repo
  - https://github.com/miraisolutions/rTRNG
- Applied example: credit default simulation
  - https://github.com/miraisolutions/PortfolioRiskMC
  - Presented at R/Finance 2017 in Chicago