R goes Mobile:
Efficient Scheduling for Parallel R Programs
on Heterogeneous Embedded Systems

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Parallel Machine Learning Algorithms

**Challenge:**
- Find the best algorithm configuration
  - Vast search space: Algorithms + Specific parameters for each
- Parameter tuning can take weeks
  - Solution: Reduce evaluations with model based optimization
  - Reduce runtime with efficient parallel execution
  - Enable larger problem sizes

**Goal:**
- Resource-aware scheduling strategy for parallel learning algorithms
R goes Mobile -
Parallelizing R on Heterogeneous Architectures

Challenge:
- Running parallel R programs on mobile heterogeneous architectures
  - Tight resources and energy restrictions
  - Parallel execution can cause inefficient utilization
  - Different processors with different frequencies
  - No support

Approach:
- Enable scheduling of parallel jobs to specific CPUs
- Use regression model for job runtime estimates
- Integrate search space exploration and scheduling

Goal:
- Resource-aware scheduling strategies for parallel R program on embedded devices
Heterogeneous Architectures
Odroid XU3 - Used in Mobile Phones

ARM big.LITTLE System
* 4 x big - Cortex A15 up to 2.0 GHz
* 4 x little - Cortex A7 up to 1.2 GHz

GPU: Mali-T628
* OpenGL ES 3.0/2.0/1.1

Memory:
* 2GB LPDDR3 RAM

Power Measurement Sensors:
* 4 x TI INA231 (A15, A7, GPU, RAM)

OS:
* Linux and Android
Allocate Parallel Jobs to specific CPUs
mclapply & mcparallel

**mcparallel**
- Already supports allocation of jobs to specific CPUs with mc.affinity (R 3)
- Disadvantages
  - No controlled execution order
  - Low level

**mclapply**
- More convenient
- But no support for mapping parallel jobs to specific CPUs

**New hmclapply**
- Supports mapping to specific CPUs with cpu.affinity
- Controlled scheduling

*How to use hmclapply and what about the performance?*
Allocate Parallel Jobs to specific CPUs
Exemplary Variance Filter on a Matrix

deftools::load_all("parallMap/") # includes modified mclapply
n <- 300 # observations
p <- 20000 # covariates
X <- matrix(replicate(p, rnorm(n, sd = runif(1, 0.1, 10))), n, p)
colnames(X) <- sprintf("var_\%05i", 1:p)

bFunct = function (N){
  for (i in 1:N) {
    train <- sample(nrow(X), 2 / 3 * nrow(X))
    colVars <- apply(X[train, ], 2, var)
    keep <- names(head(sort(colVars, decreasing = TRUE), 100))
    # myAlgorithm(X[, keep])
  }
}

N = c(20,40,40,20,40,40) # different job work loads

affinity = c(4,5,6,4,5,6) # CPU 4 slow, 5 and 6 fast

hmclapply(X = N, FUN = bFunct,
          mc.cores = 3, mc.preschedule = FALSE,
          cpu.affinity = affinity)
Results on Heterogeneous Architectures: mclapply vs hmclapply

\[ mclapply - \text{ variance of completion times} \]  
\[ \rightarrow 257 \ (\pm 1.5) \ \text{seconds} \]

\[ hmclapply - \text{ balanced times} \]  
\[ \rightarrow 234 \ (\pm 1.0) \ \text{seconds} \]

→ Efficient job allocation optimizes the overall execution time

Problem

→ Efficient scheduling needs to know the runtime of a job for each available processor type
Solution:
Runtime Estimation via Regression Model

Resource estimates are used to guide scheduling strategies
Performance Estimation to Prioritize Parallel Jobs

**Runtime**

- Cost vs. Time

**Classification Error: Performance**

- Gamma vs. Cost
- MMCE vs. Cost

**Short Runtime**

- High Performance
Resource-Aware Model-Based Optimization

H. Kotthaus et. al.: RAMBO: Resource-Aware Model-Based Optimization with Scheduling for Heterogeneous Runtimes and a Comparison with Asynchronous Model-Based Optimization. Learning and Intelligent Optimization 2017 (LION 11) (accepted for publication)
Benchmark for the Heterogeneous Mobile Architecture Odroid

Objective Function
- Ackley function
- Highly multi modal
- Goal: find the parameter configuration that produces the smallest $y$

Runtime Function
- Rosenbrock function
- Smooth surface simulates execution times of parallel jobs
Runtime Estimation via Regression Model
Rosenbrock 2D Function on Odroid

Fast CPU Cortex A15

Slow CPU Cortex A7

Estimated Runtime

Executed Runtime

Run time of evaluated configurations

X1

X2

X1

X2

X1

X2

X1

X2
Scheduling Snippet

→ **RAMBO manages to balance parallel jobs more evenly on heterogeneous architectures**
Who Finds the Best Configuration First?

→ **RAMBO converges faster to the optimum (lower is better) on the heterogeneous architecture**
Summary

Efficient Scheduling for Parallel R Programs on Heterogeneous Embedded Systems

- CPU affinity parameter to allocate parallel jobs to specific CPUs
- Model for estimating execution times for different processor types
- Faster parallel machine learning on heterogeneous architectures

We are also on github:

- TraceR Profiling for Parallel R Programs
  → https://github.com/allr/tracer
- Benchmarks
  → https://github.com/allr/benchR
- RAMBO – Ressource-Aware Model-Based Optimization
  → https://github.com/mlr-org/mlrMBO/tree/smart_scheduling