YARV

Past, Present and Future

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RUBY MEETS VM

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Point of This Presentation

Merging YARV is not a goal,
but a start

YARV: Yet Another RubyVM

Notice

- I can’t speak English well, so I write down all things what I want to say.
  - Do you get ready for opera glasses?
  - Unfortunately, some slides are written in Japanese
- You can ask questions with

  Japanese, C, Ruby, …, or slow/short English.
- “How to impl. Ruby”, not “How to use Ruby”
- “x50” is too big mouth
  - Maybe x20

Self Introduction

- Koichi (given name) Sasada (family name)
  - ささだ（family name) こういち (given name)
  - 笹田 (family name) 耕一 (given name)
- Lecturer @ University of Tokyo (Feb. 2008-)
- Only VM developer
  - Don’t have compatibility with Matz
  - Please call me “ko-i-chi”

Agenda

- History of YARV
- Advanced VM Topics
  - Performance
    - Parallel Thread Execution
    - Embedding Float Value
    - JIT Compiler
    - Pre-Compiler
      - “Ruby to Compiled file” Compiler
      - “Ruby to C” Compiler
  - New Feature
    - Multi-VM Creation
    - Customizable Ruby Core
    - Debug/Profile support feature
- Summary

History of YARV

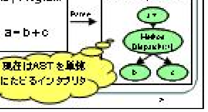
- 4 Years
  - **1, Jan 2004 Project Start**
  - 2004-2005 VM Core, Optimization
    - Supported by MITO youth Project (IPA)
  - 2005-2006 Thread, etc
    - Supported by MITO Project (IPA)
    - 1, Apr 2006 Got a Job (Assistant on U-Tokyo)
  - 2006-2007 etc, etc
    - Supported by MITO Project (IPA)
    - 25, Dec 2007 Got a Ph.D
  - **25, Dec 2007 (GMT) 1.9 Release**

FYI

- Ruby 2.0 – since 2003 3/31
- Perl 6 – since 2003 4/1

YARV Policy

- Performance
  - Speed, Speed, Speed
  - Applied many many many optimization Tech.
- Compatibility
  - C extension API
  - Not language compatibility
- Auto-generation
  - VM description to Concrete VM source code



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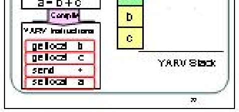

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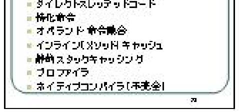
- ダイレクトスレッデッドコード
- 特化命令
- オペランド・命令融合
- インライン(メソッド)キャッシュ
- 静的スタックキャッシング
- プロファイラ
- ネイティブコンパイラ(不完全)

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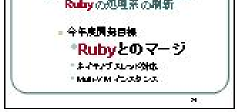
Rubyの処理系の刷新

- 今年度開発目標
  - Rubyとのマージ
  - ネイティブスレッド対応
  - Multi-VM インスタンス

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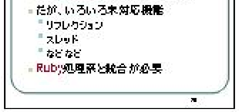
- だが、いろいろ未対応機能
  - リフレクション
  - スレッド
  - などなど
- Ruby処理系と統合が必要

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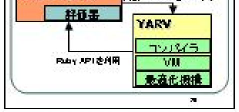

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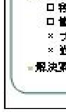

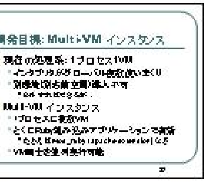
開発目標: Multi-VM インスタンス

- 現在の処理系: 1プロセス1VM
  - インタプリタがグローバル変数使いまくり
  - 別環境(別名前空間)導入不可
- Multi-VM インスタンス
  - 1プロセスに複数VM
  - とくにRuby組み込みアプリケーションで有効
    - たとえばmod_ruby (apache extension) など
  - VM同士を並列実行可能

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開発目標: Multi-VM インスタンス イメージ図

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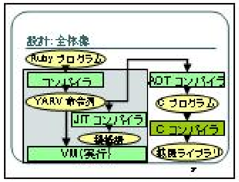
設計: 全体像

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設計: YARV命令セット

- 現時点では 52 命令
  - できるだけシンプルに
  - → VM生成系によって自動的に変換・最適化命令を C
- プリミティブ型がないため、数値演算命令無し

```
a = recv.method(b)
getlocal 2 # push recv
getlocal 1 # push b
send method, 1
setlocal 1 #
```

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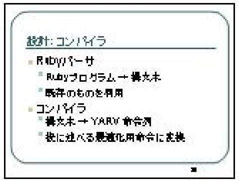
設計: コンパイラ

- Rubyパーサ
  - Rubyプログラム → 構文木
  - 既存のものを利用
- コンパイラ
  - 構文木 → YARV 命令列
  - 後に述べる最適化用命令に変換

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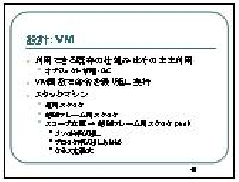
設計: VM

- 利用できる既存の仕組みはそのまま利用
  - オブジェクト管理・GC
- VM関数で命令を繰り返し実行
- スタックマシン

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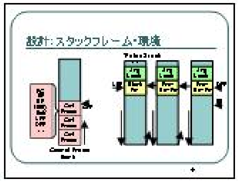
設計: スタックフレーム・環境

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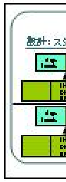

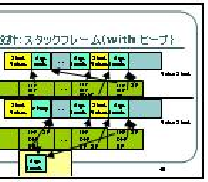
設計: スタックフレーム(with ヒープ)

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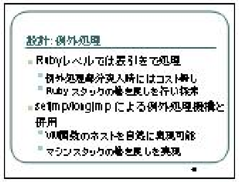
設計: 例外処理

- Rubyレベルでは表引きで処理
  - 例外処理範囲突入時にはコスト無し
  - Ruby スタックの巻き戻しを行い検索
- setjmp/longjmp による例外処理機構と併用
  - VM関数のネストを自然に実現可能
  - マシンスタックの巻き戻しを実現

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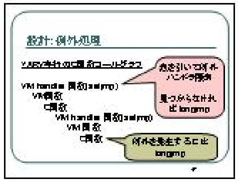
設計: 例外処理

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設計: データ構造

- Rubyマージのために刷新
  - とくに評価器
  - グローバル変数の排除(Thread へ格納)
  - スタックフレームのスリム化

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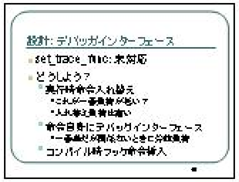
設計: デバッガインターフェース

- set_trace_func: 未対応
- どうしよう?
  - 実行時命令入れ替え
  - 命令自体にデバッグインターフェース
  - コンパイル時フック命令挿入

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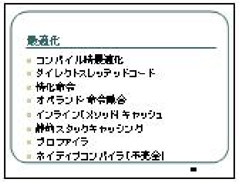
最適化

- コンパイル時最適化
- ダイレクトスレッデッドコード
- 特化命令
- オペランド・命令融合
- インライン(メソッド)キャッシュ
- 静的スタックキャッシング
- プロファイラ
- ネイティブコンパイラ(不完全)

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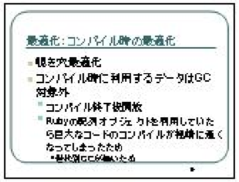
最適化: コンパイル時の最適化

- 覗き穴最適化
- コンパイル時に利用するデータはGC対象外
  - コンパイル終了後開放
  - Rubyの既存オブジェクトを利用していたら巨大なコードのコンパイルが極端に遅くなってしまったため
    - 世代別GCが欲しかった

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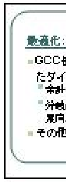

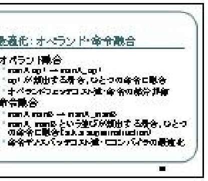
最適化: オペランド・命令融合

- オペランド融合
  - insnA op1 → insnA_op1
  - op1 が頻出する場合, ひとつの命令に融合
  - オペランドフェッチコスト減・命令の動的特化
- 命令融合
  - insnA; insnB → insnA_insnB
  - insnA, insnB という並びが頻出する場合, ひとつの命令に融合 (a.k.a. superinstruction)
  - 命令ディスパッチコスト減・Cコンパイラでの最適化

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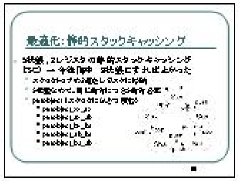
最適化: 静的スタックキャッシング

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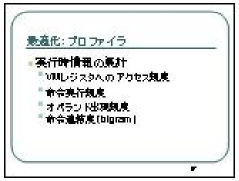
最適化: プロファイラ

- 実行時情報の集計
  - VMレジスタへのアクセス頻度
  - 命令実行頻度
  - オペランド出現頻度
  - 命令連続度 (bigram)

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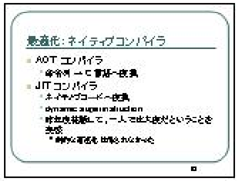
最適化: ネイティブコンパイラ

- AOT コンパイラ
  - 命令列 → C 言語へ変換
- JIT コンパイラ
  - ネイティブコードへ変換
  - dynamic superinstruction

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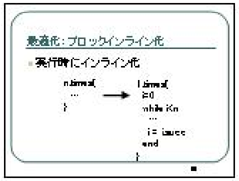
最適化: ブロックインライン化

- 実行時にインライン化

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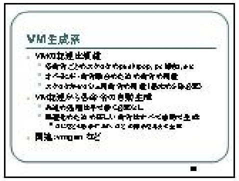
VM生成系

- VMの記述を簡潔
- VM記述から各種命令の自動生成
- 関連: vmgen など

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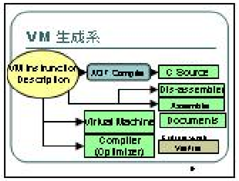
VM 生成系

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VM生成系: スタックキャッシング用命令生成

- プッシュ・ポップ処理をSC用レジスタアクセスに
- コンパイラは命令列を状態遷移に則り変換

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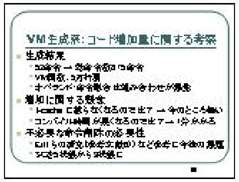
VM生成系: コード増加量に関する考察

- 生成結果
- 増加に関する懸念
- 不必要な命令削除の必要性

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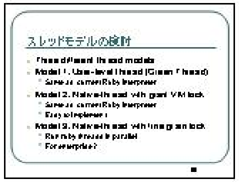
スレッドモデルの検討

- Thread Model
  - Model 1: User-level thread (Green Thread)
    - Same as current Ruby Interpreter
  - Model 2: Native thread with giant VM lock
    - Same as current Ruby Interpreter
    - Easy to implement
  - Model 3: Native thread with fine grain lock
    - Run ruby threads in parallel
    - For enterprise?

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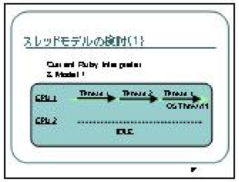
スレッドモデルの検討(1)

Current Ruby Interpreter & Model 1

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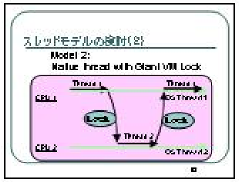
スレッドモデルの検討(2)

Model 2: Native thread with Giant VM Lock

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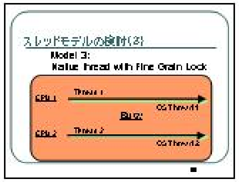
スレッドモデルの検討(3)

Model 3: Native thread with Fine Grain Lock

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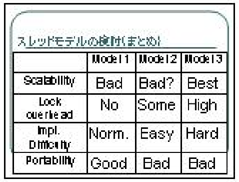
スレッドモデルの検討(まとめ)

	Model 1	Model 2	Model 3
Scalability	Bad	Bad?	Best
Lock overhead	No	Some	High
Impl. Difficulty	Norm.	Easy	Hard
Portability	Good	Bad	Bad

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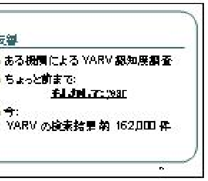
反響

- ある機関による YARV 認知度調査
- ちょっと前まで:
  - もしかして: year
- 今:
  - YARV の検索結果 約 162,000 件

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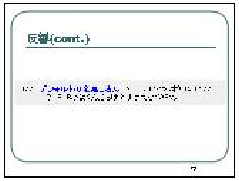
反響(cont.)

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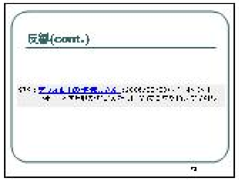
反響(cont.)

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成果(1) Rubyとのマージ

- 現在のRubyの機能を「ほぼ」網羅
- YARV 0.4.0 リリース (2006/02/22)
  - ビルド・インストール可能
  - Ruby 1.9 (2006/02/14) 版に追従

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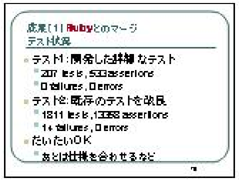
成果(1) Rubyとのマージ
テスト状況

- テスト1: 開発した詳細なテスト
  - 207 tests, 533 assertions
  - 0 failures, 0 errors
- テスト2: 既存のテストを改良
  - 1811 tests, 13358 assertions
  - 14 failures, 0 errors
- だいたいOK
  - あとは仕様を合わせるなど

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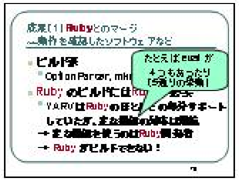
成果(1) Rubyとのマージ
—動作を確認したソフトウェアなど

- ビルド系
  - OptionParser, mk…
- Ruby のビルドには Ru…
  - YARV は Ruby のほとんどの動作をサポートしていたが, まだ…
  - → Ruby がビルドできない!

たとえば eval が 4つもあったり (5通りの挙動)

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成果(1) Rubyとのマージ
—動作を確認したソフトウェアなどのごく一部

- Web系
  - Ruby on Rails
  - tDiary
  - ERB
  - Hiki
- 拡張系
  - OpenGL
  - Ruby/SDL
  - rcairo

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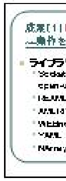
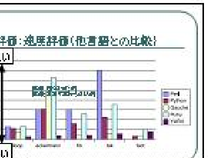
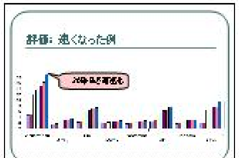
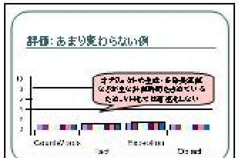
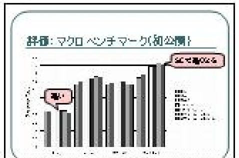
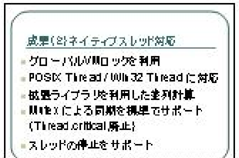



評価: 速度評価(他言語との比較)

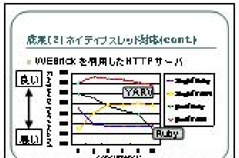

評価: 速くなった例


評価: あまり変わらない例


評価: マクロベンチマーク(初公開)


成果(2) ネイティブスレッド対応

- グローバルVMロックを利用
- POSIX Thread / Win32 Thread に対応
- 拡張ライブラリを利用した並列計算
- Mutex による同期を標準でサポート (Thread.critical 廃止)
- スレッドの停止をサポート

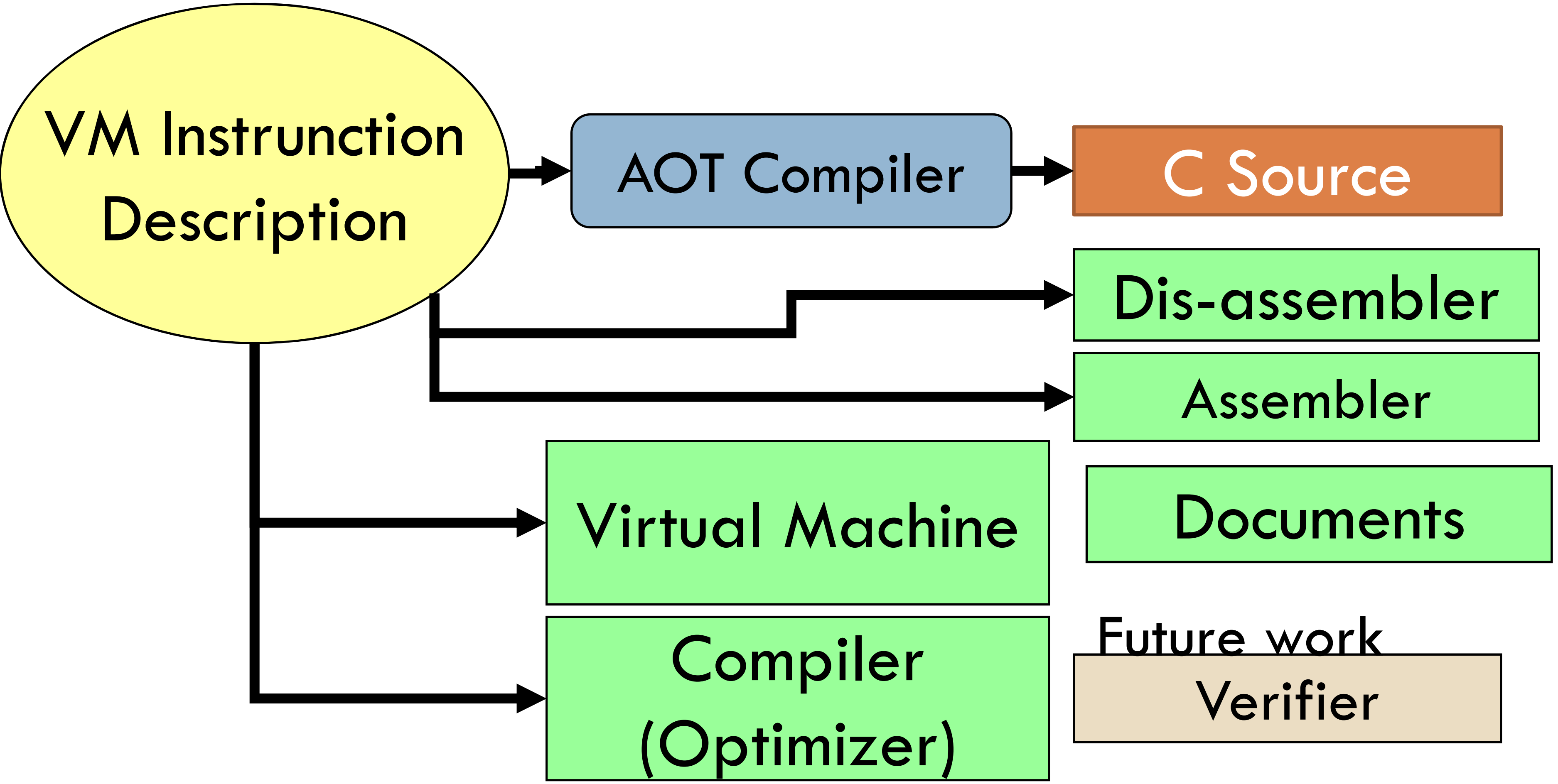

成果(2) ネイティブスレッド対応(cont.)

- WEBrick を利用したHTTPサーバ

成果(2) ネイティブスレッド対応(cont.)
拡張ライブラリと組み合わせた並列計算

Native thread with Giant VM Lock

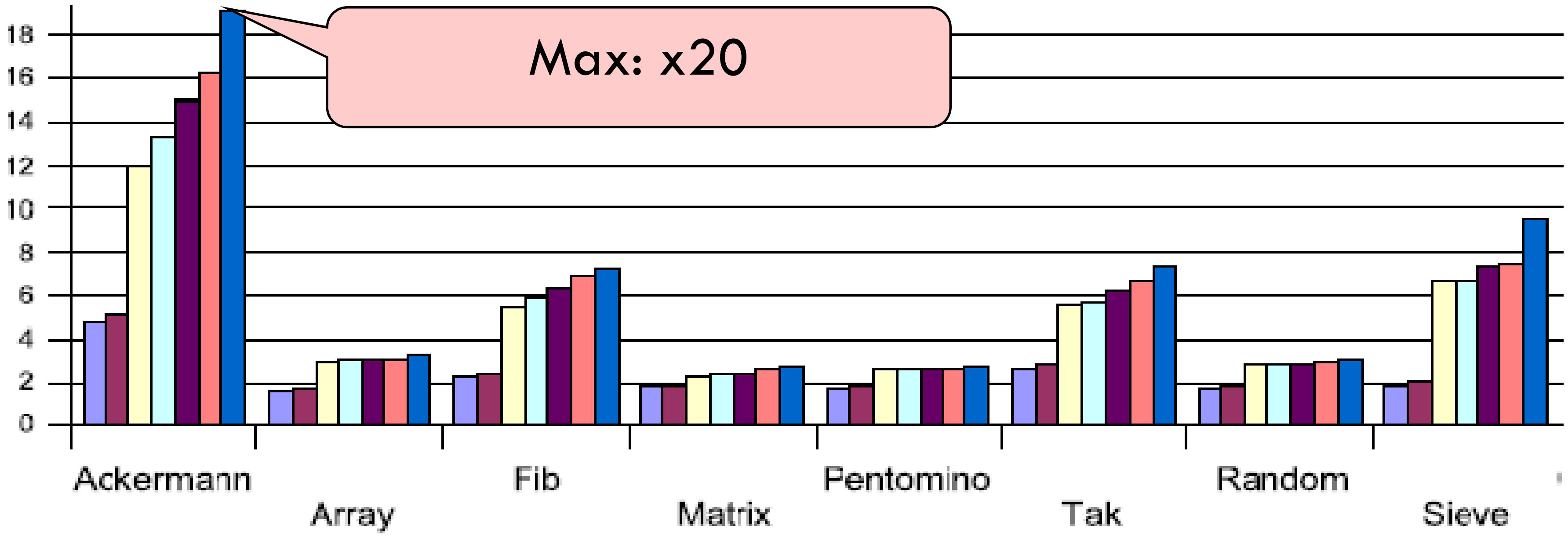
VM Generator



Enemies of YARV

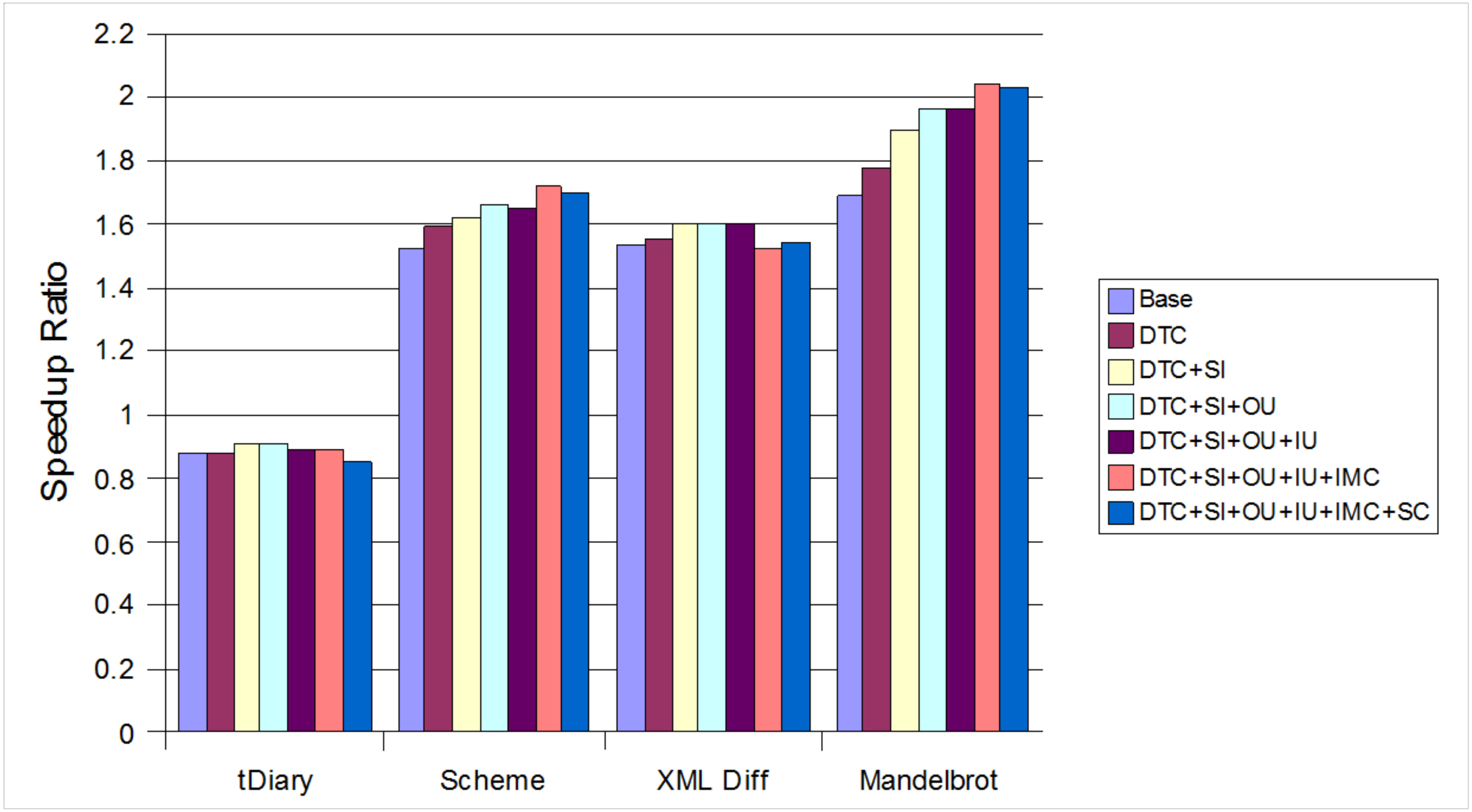
- Ruby Specification ≒ Matz
  - Ruby Spec kills many optimization techs
  - We love "Dynamic" "Meta" Programming, but…
- Changing Spec is also Nightmare
- Portability
  - We can't use system depending techs.
- Rivals **(not Enemy)**
  - Jruby, Rubinius, IronRuby, …
- Peggy work on my Job

Evaluation: Improve case

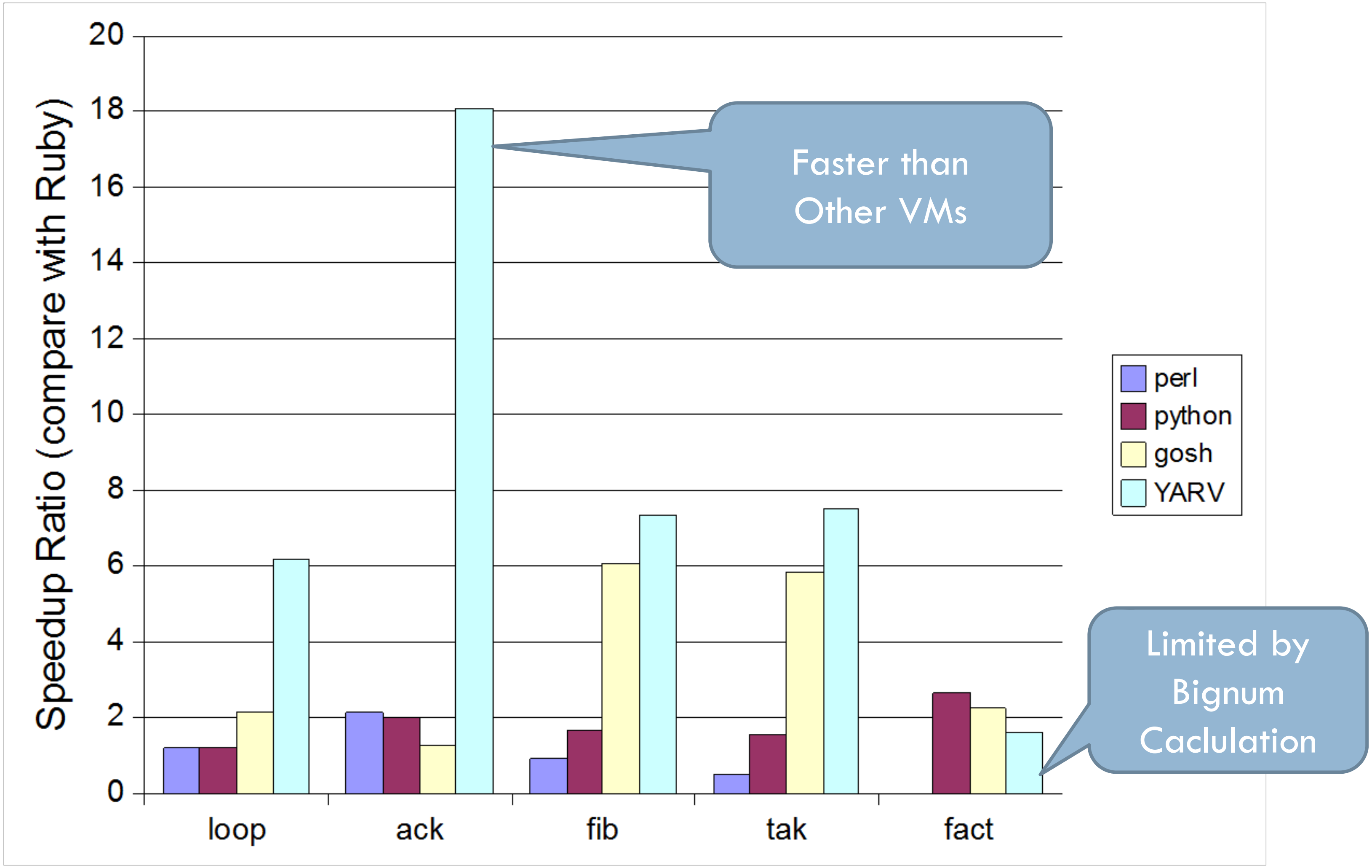


Max: x20

Evaluation: Macro-Benchmark



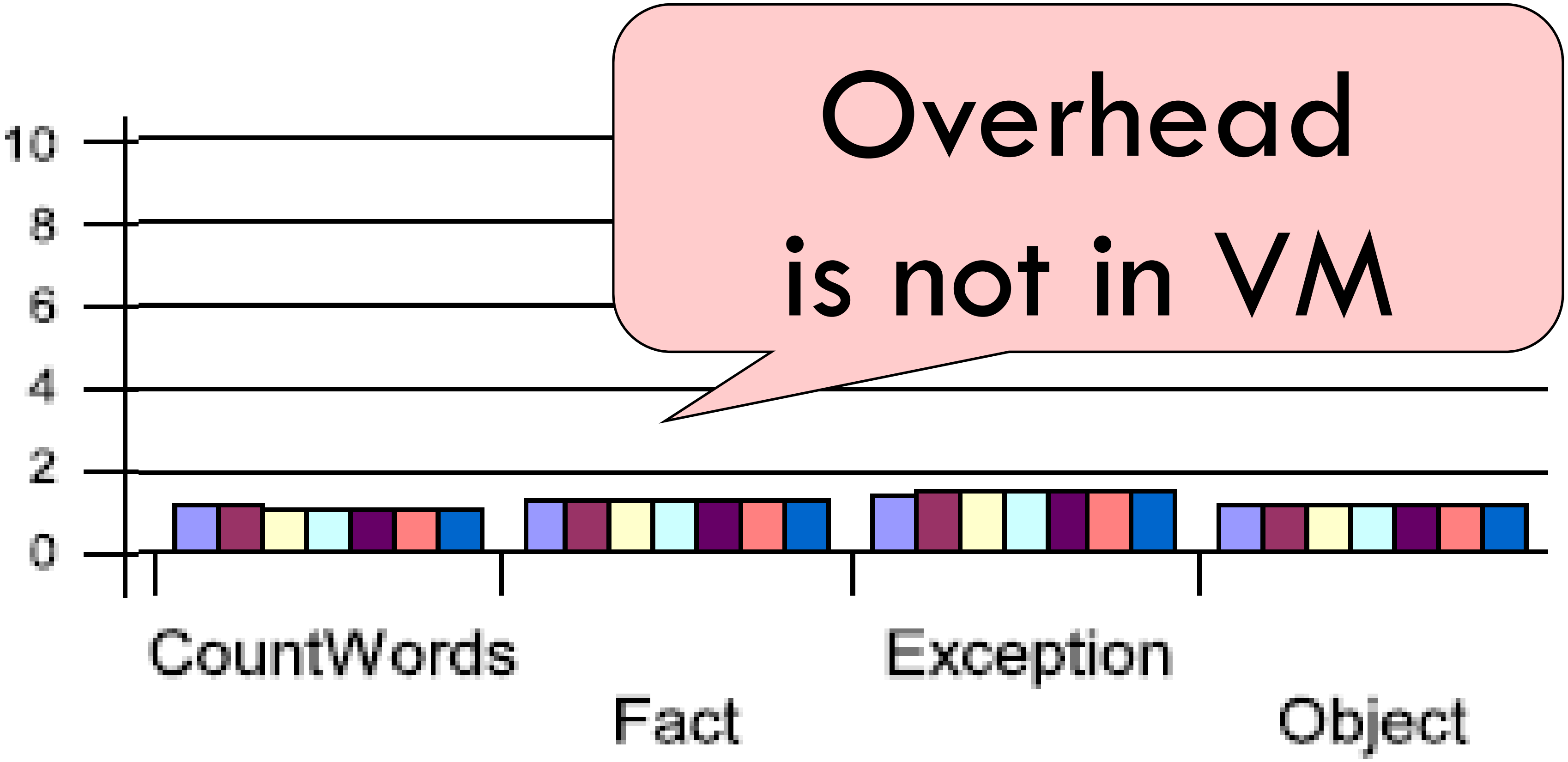
Evaluation: Compare with Other Languages



Faster than Other VMs

Limited by Bignum Caclulation

Evaluation: VM doesn't affect

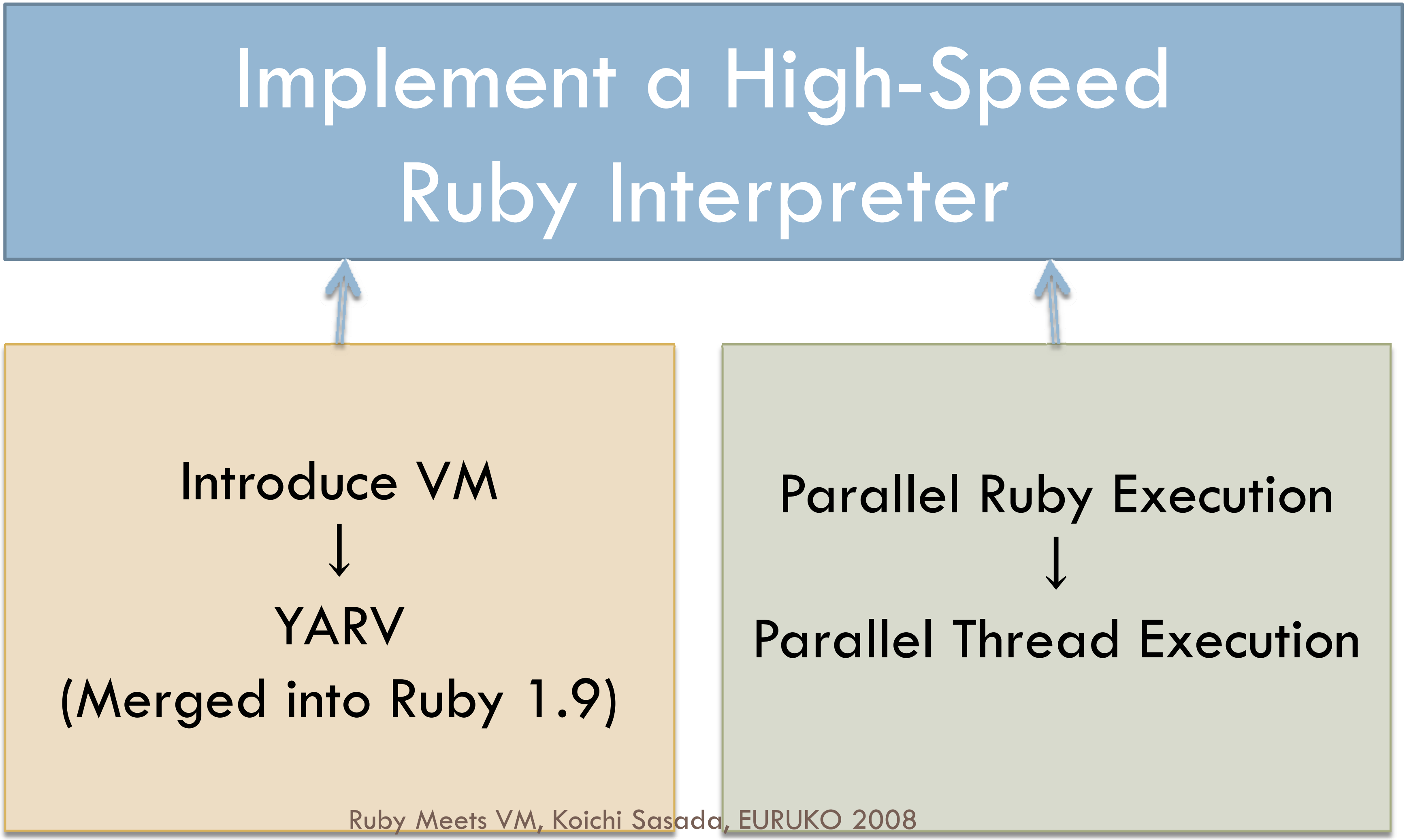


Overhead is not in VM

Advanced VM Topics

- Performance
  - Parallel Thread Execution
  - Embedding Float Value
  - JIT Compiler
  - Pre-Compiler
    - “Ruby to Compiled file” Compiler
    - “Ruby to C” Compiler
- New Feature
  - Multi-VM Creation
  - Customizable Ruby Core
  - Debug/Profile support feature

Ph.D Thesis
Efficient Implementation of Ruby Virtual Machine



Implement a High-Speed Ruby Interpreter

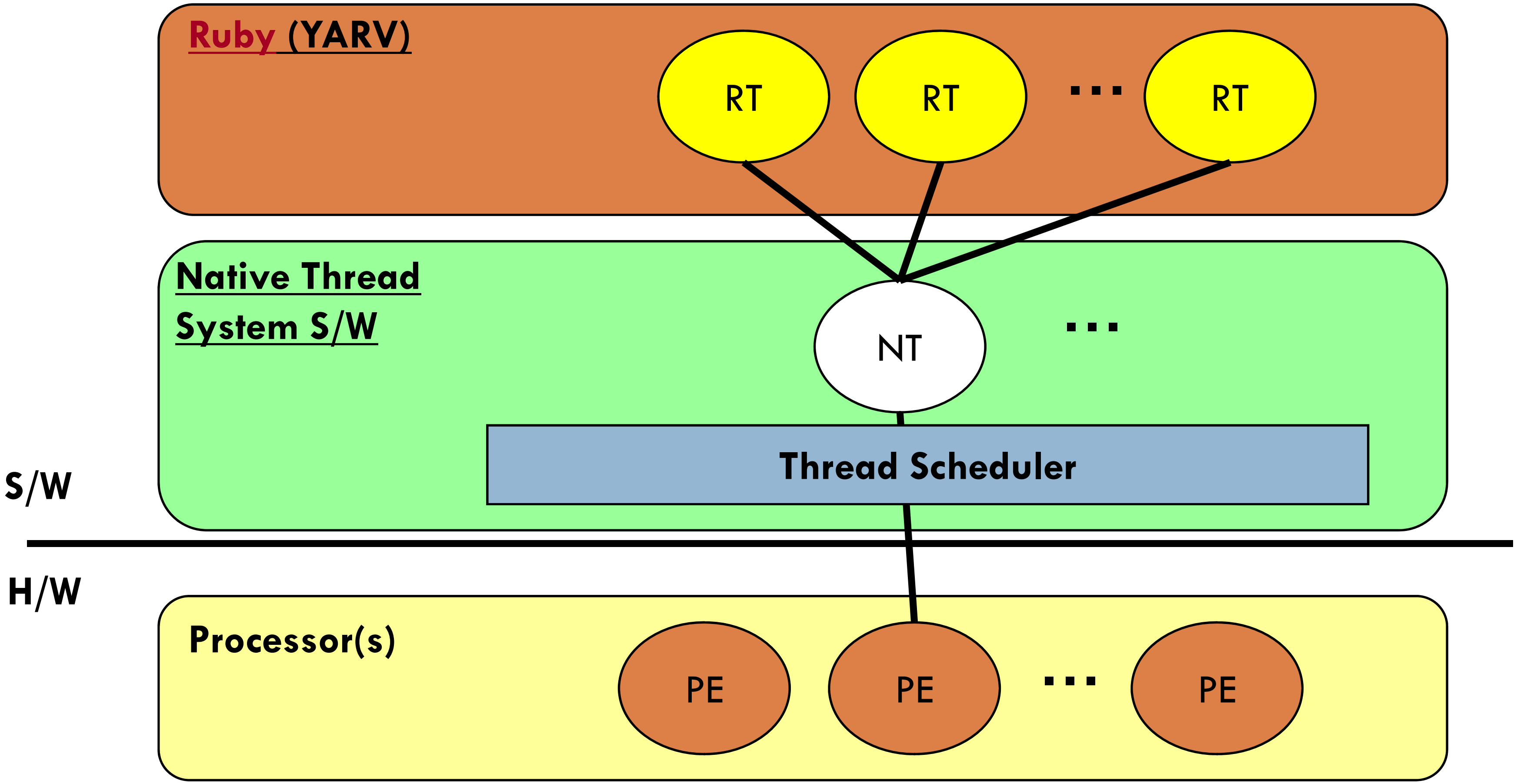
Introduce VM
↓
YARV
(Merged into Ruby 1.9)

Parallel Ruby Execution
↓
Parallel Thread Execution

Parallel Thread Execution

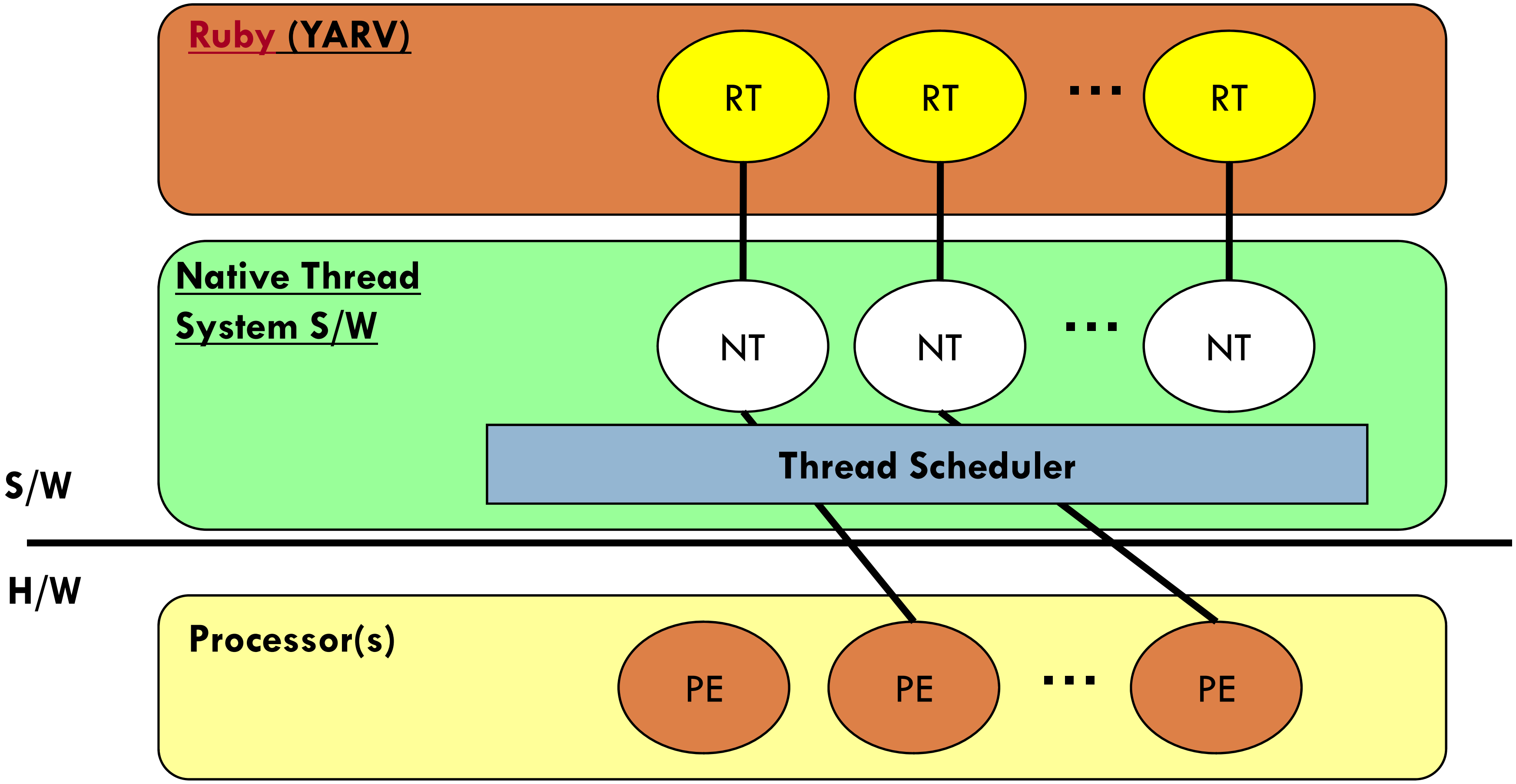
- Using Native Thread
- Get rid of Giant VM Lock

Method (1)
Ruby Thread and Native Thread (1:N) a.k.a -1.8 Ruby model



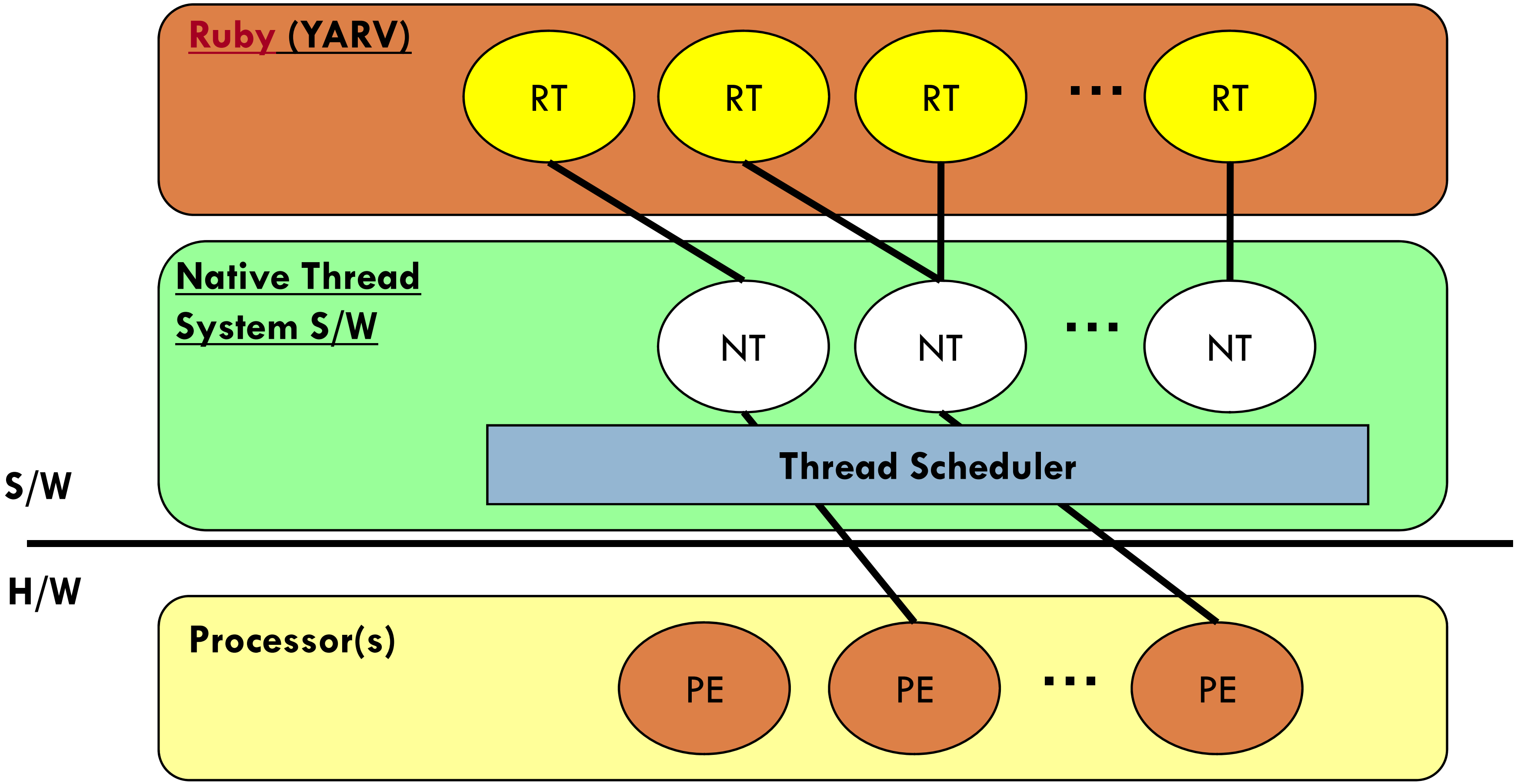
PE: Processor Element, UL: User Level, KL: Kernel Level

Method (2)
Ruby Thread and Native Thread (1:1)



PE: Processor Element, UL: User Level, KL: Kernel Level

Method (3)
Ruby Thread and Native Thread (N:M)



PE: Processor Element, UL: User Level, KL: Kernel Level

Discussion

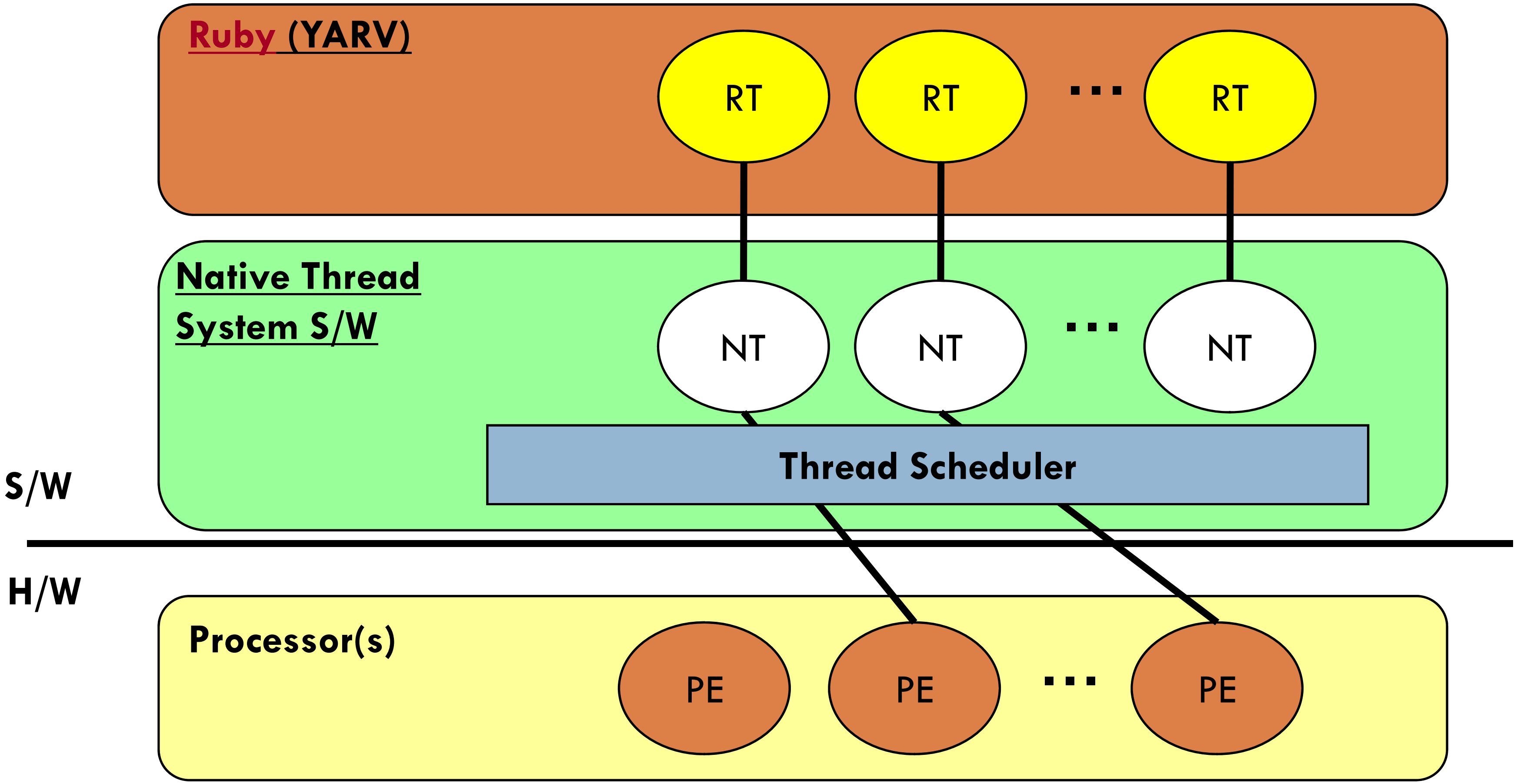
Ruby Thread and Native Thread

- Mapping with Native Thread and Ruby Thread

	Pros	Cons
1:N	Lightweight Thread Control	Can’t run in Parallel
1:1	Run in Parallel Simple, Portable	Heavyweight Thread Control (Creation, etc)
N:M	Lightweight Thread Control, Run in Parallel	Complication, Non-Portable

- Accept 1:1 model to make Ruby Simple
  - Depend Performance on Native Thread Libraries

Accepted Method:
Ruby Thread and Native Thread (1:1) ← Ruby 1.9/YARV



PE: Processor Element, UL: User Level, KL: Kernel Level

Introduction of Mutual Exclusion

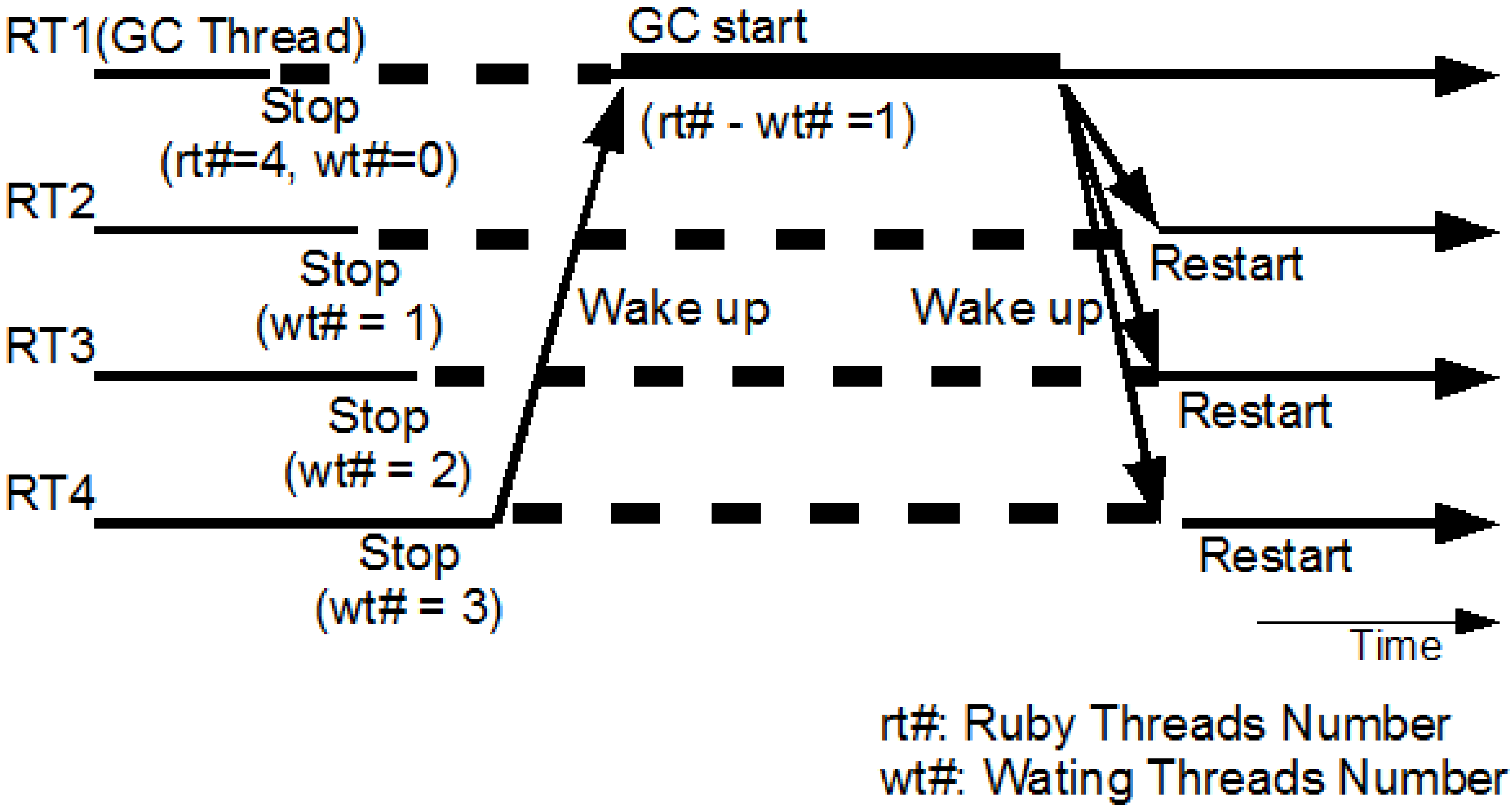
- Needed at
  1. Global VM Management Data
  2. Object Management / GC
  3. Inline Cache
  4. Thread Unsafe “C” methods

(1) Global VM Management Data

- Managed by Table
  - Variable Name → Value
  - Method Name → Method Body
  - …
- Introduce Synchronization at Table Operation
  - Get/Set
  - Easy

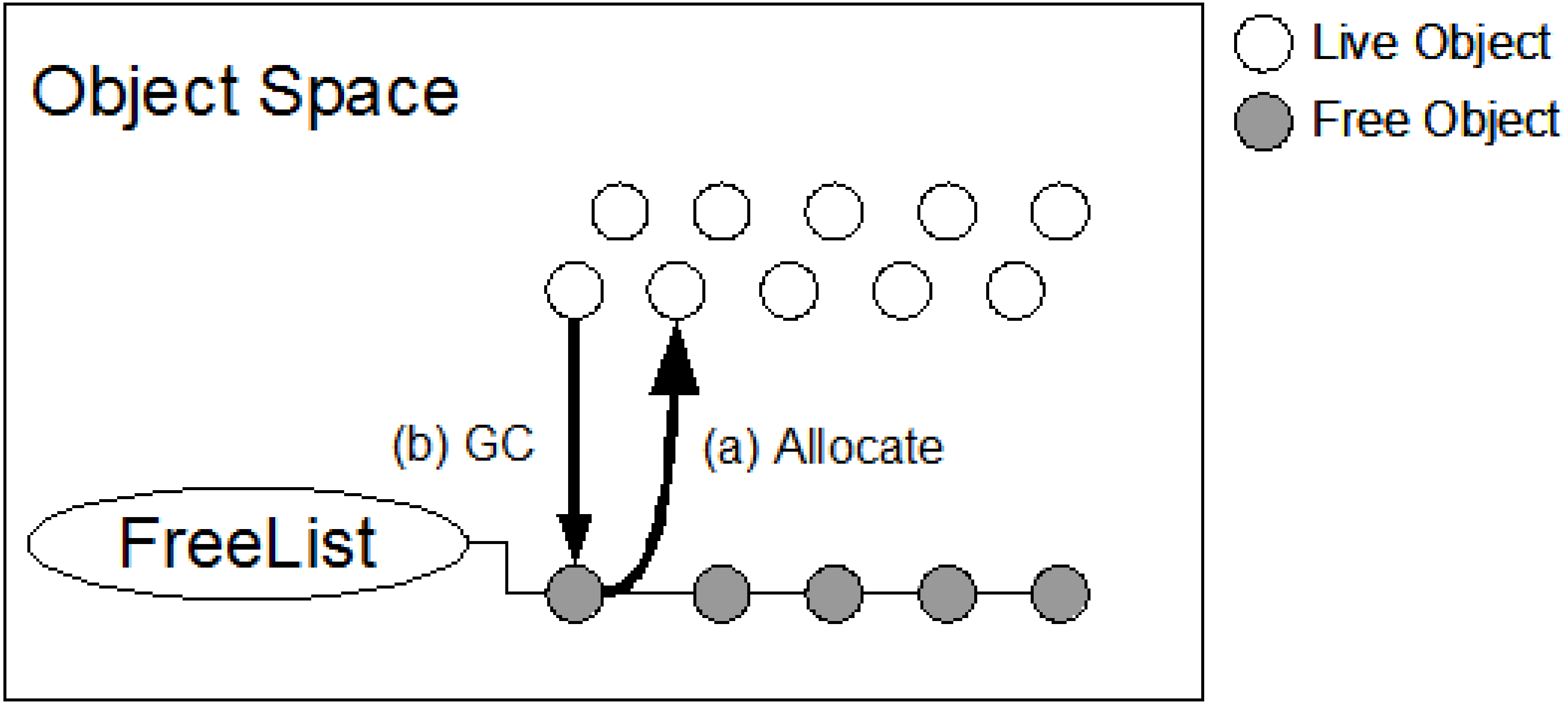
(2) Object Management/GC

- Synchronous GC

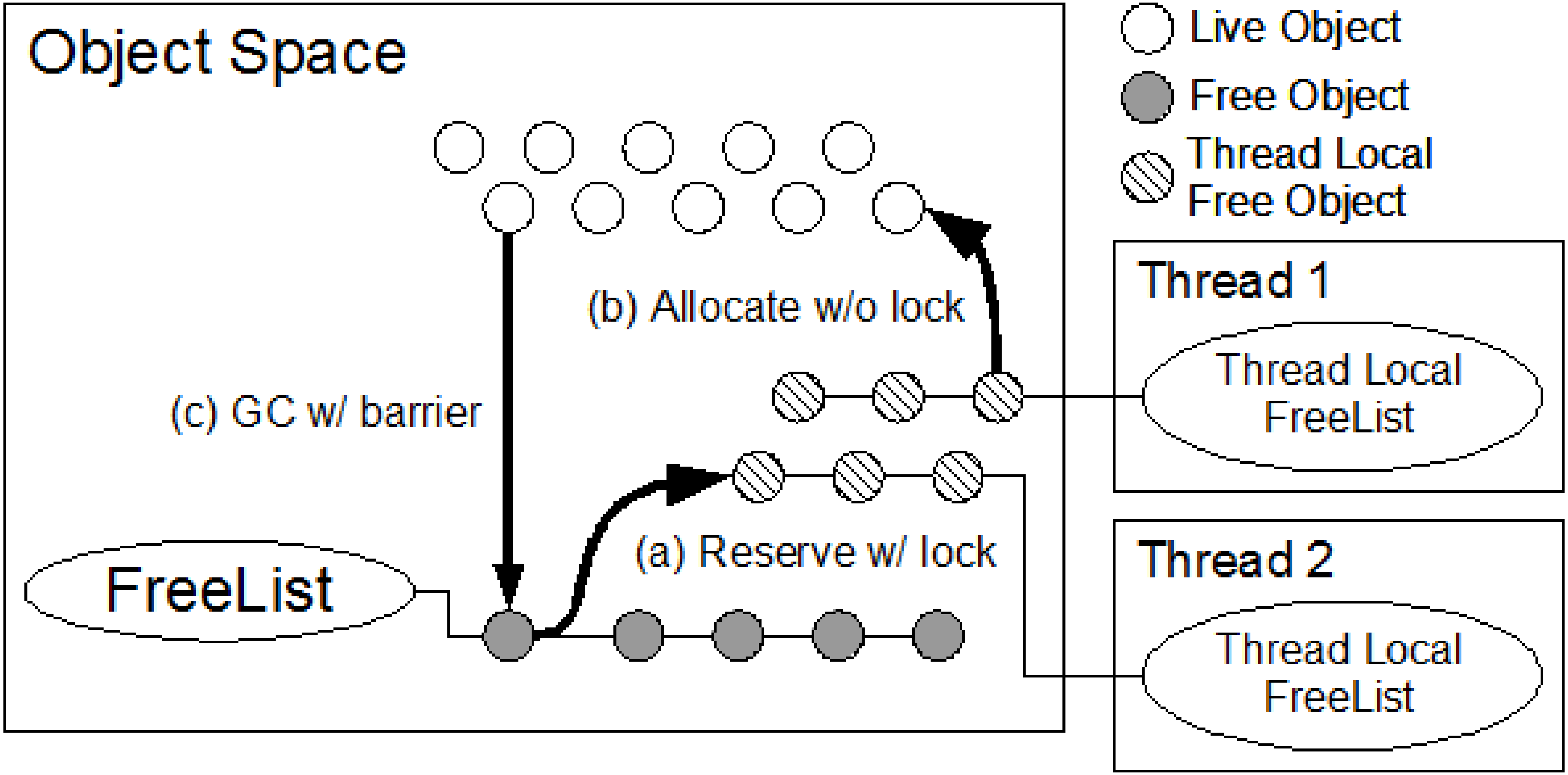


(2) Object Management

Lock-Free Object Allocation with Thread Local Free List



(2) Object Management
Lock-Free Object Allocation with Thread Local Free List



(3) Inline Cache

- Using by VM performance
  - Embed Cache Entries in Instruction Sequence
- Sync. For Coherence -> Performance Problem
  - Key and Value of Cache Entry
- Sync.-Free Inline Cache
  - Cache Miss -> Make a new entry
    - GC will clean-up old cache entries
    - Increase Miss-Penalty, but Good for average

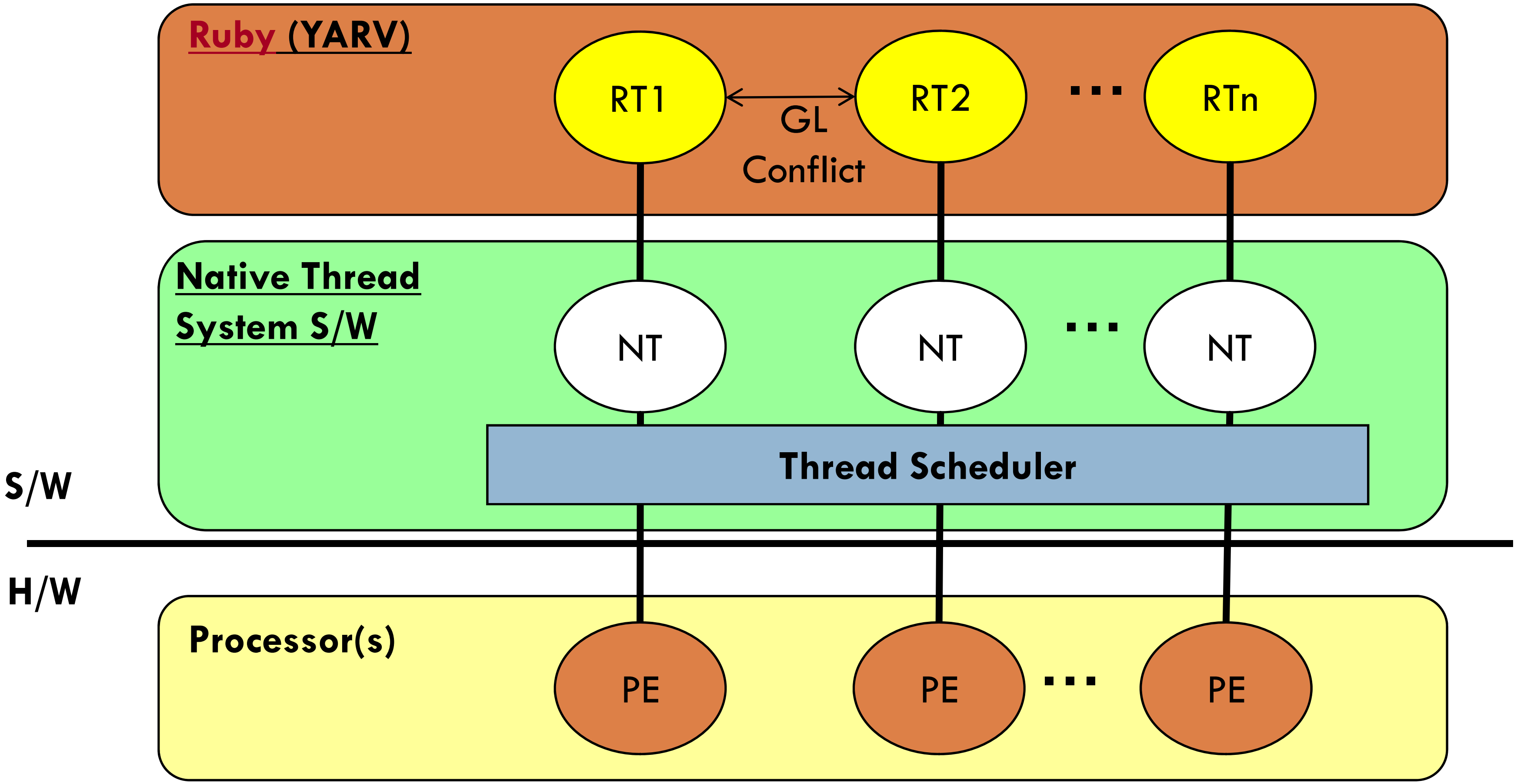
(4) Thread Unsafe “C” Methods

- CRuby has many many methods implemented by “C”
  - All of them are “Thread Unsafe”
  - Because -1.8 doesn’t support parallelization
- Basic Policy: Using Giant-Lock
  - Invoke old “C” method with Giant-Lock Acquire
  - Re-write C methods as Thread Safe, this method will be Giant-Lock free

Problem
Conflict of Giant-Lock Acquirement

- GL Conflict → Performance Decrement
- Limit Running CPU
  - Check GL Conflict Periodically
  - Limit their CPU
  - Using pthread_setaffinity_np on NTPL
    - SetThreadAffinityMask on Windows

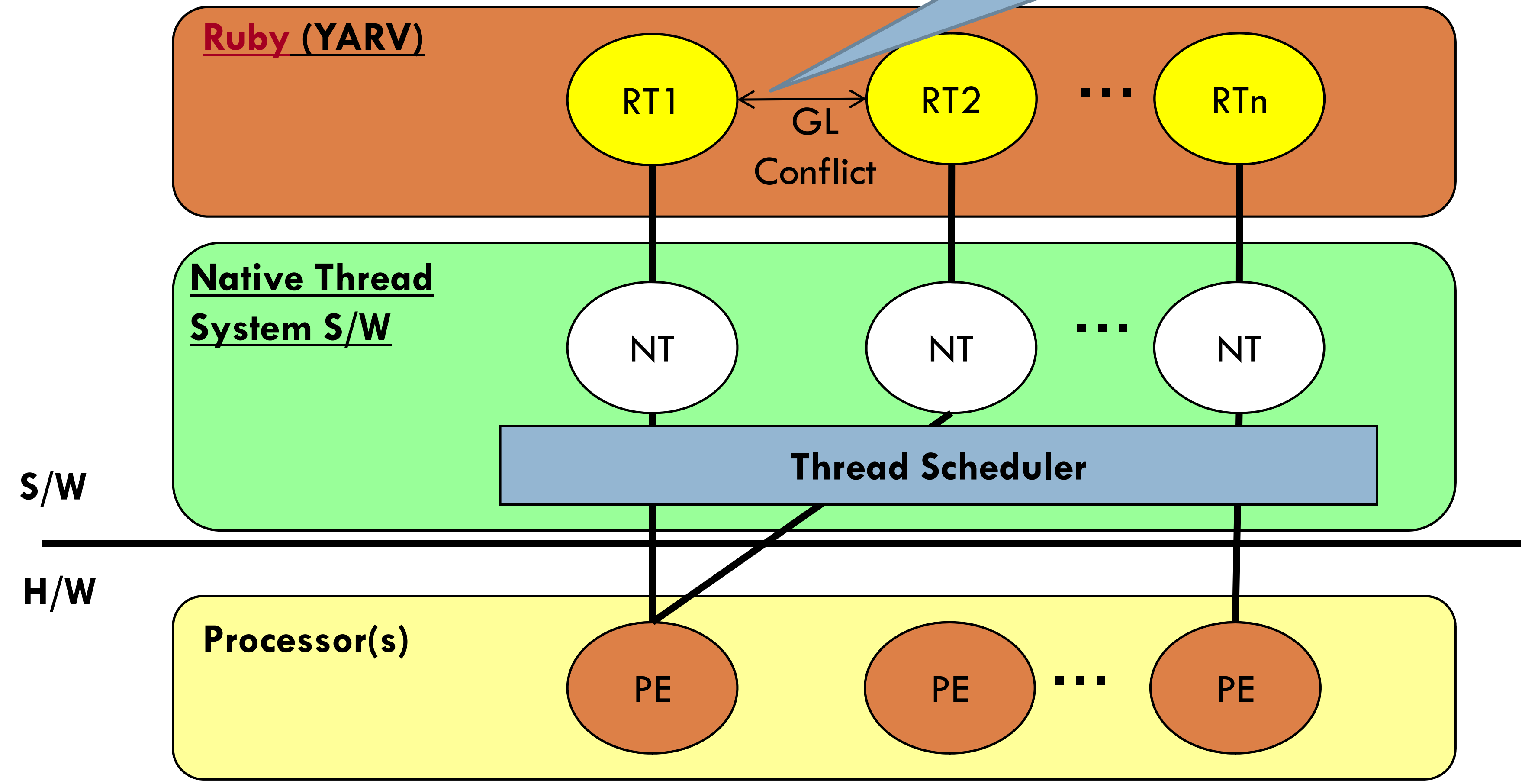
Running CPU Limitation



PE: Processor Element, UL: User Level, KL: Kernel Level

Running CPU Limitation

Force to run RT1 and RT2 in Serial
→Avoid Conflict



PE: Processor Element, UL: User Level, KL: Kernel Level

Performance Evaluation Environment

- Evaluation Environment
  - CPU: Intel Xeon CPU E5335 2.0GHz

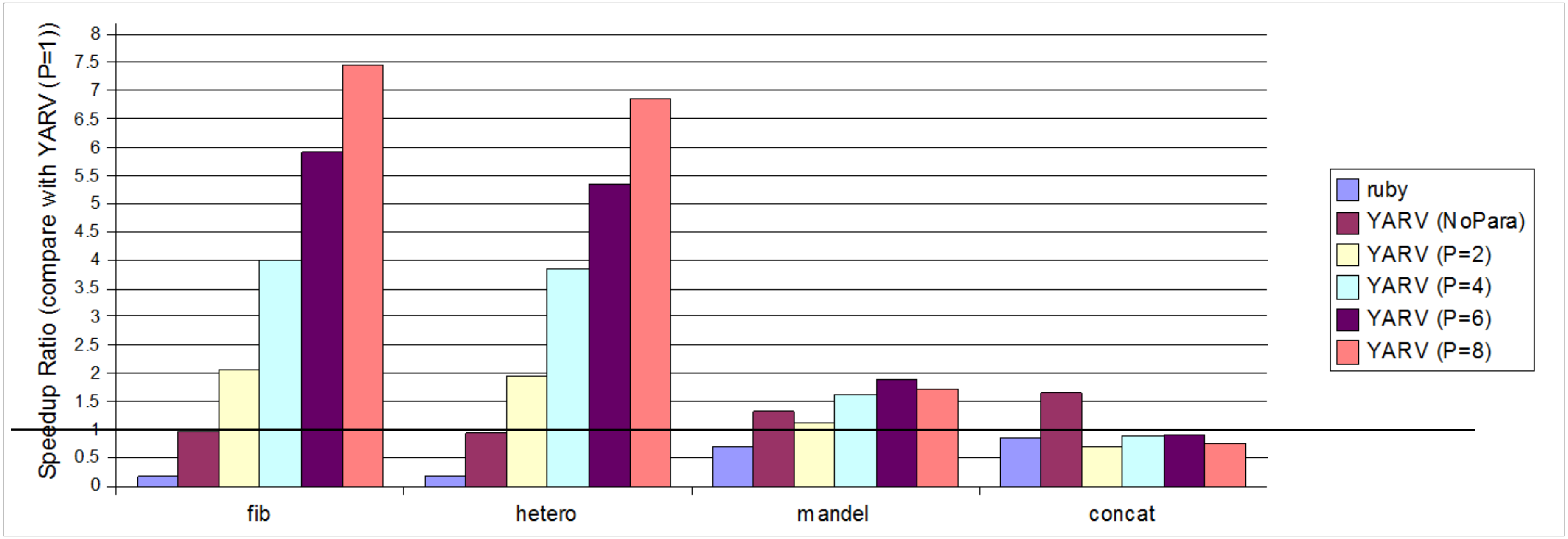
    Quad core x 2 = 8 core
  - OS: GNU/Linux 2.6.18 x86_64 SMP / NPTL
  - Compiler: gcc version 4.1.2
- Ruby
  - ruby 1.8.6 (2007-11-02) [x86_64-linux]
- YARV Optimization
  - All except Unification, Stack caching

Evaluation
Thread control Primitives

- Creation, Switch: 0.1M, Mutual Exclusion: 1M
- Low Performance for Creation/Join because of Native Thread
  - Native Thread Overhead
  - Memory Allocation Overhead
- High Performance Synchronization
- High Performance Thread Context Switch
  - Independent Stack-Depth (1.8 depends on depth)

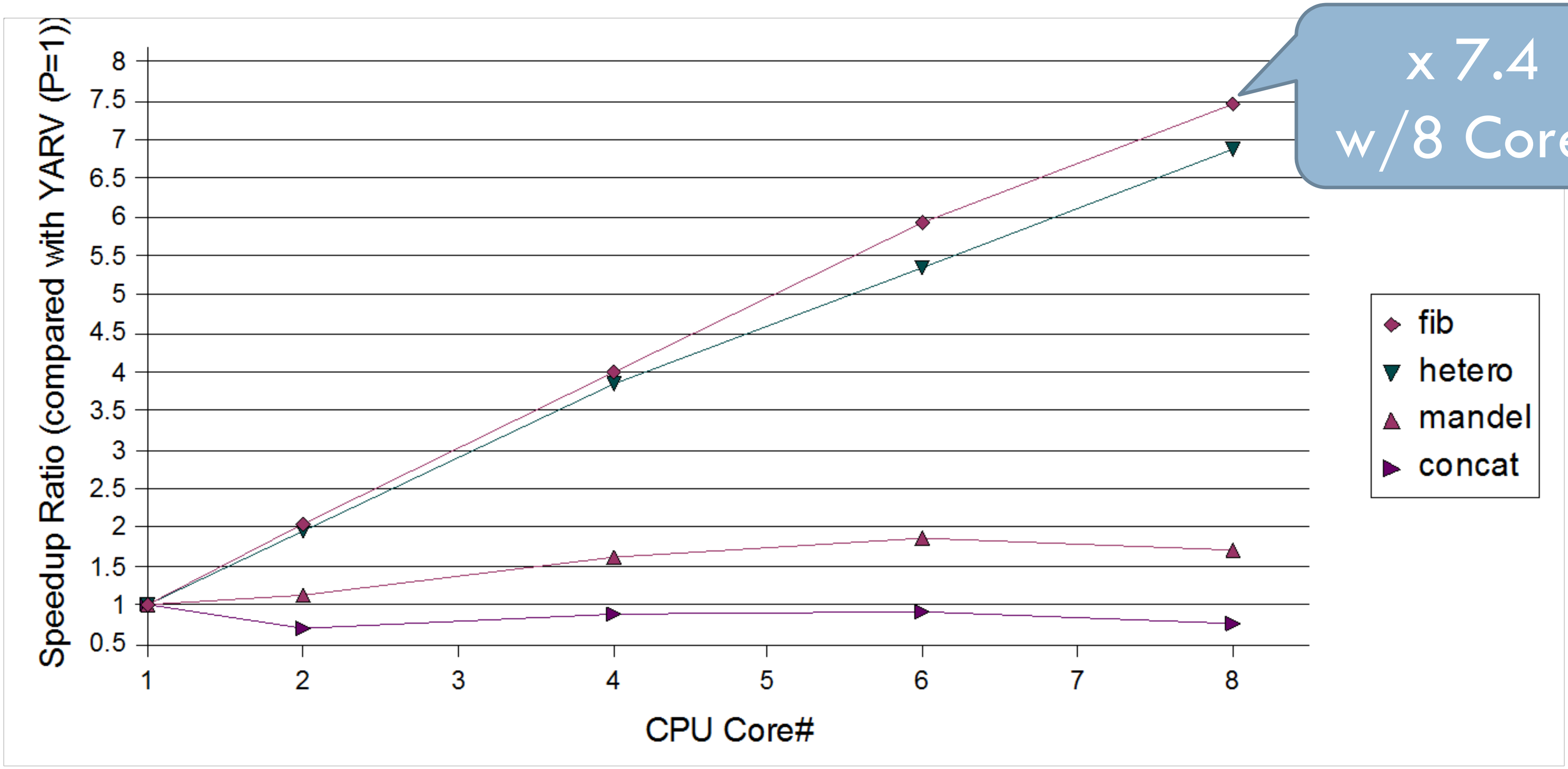
	Ruby (sec)	YARV (sec)	Ratio	NTPL (sec)
Creation	0.89	1.95	0.46	0.59
Mutual Exclusion	0.67	0.38	1.76	-
Switch (depth:1)	6.01	0.06	100.17	-
Switch (depth:16)	11.55	0.06	192.5	-

Evaluation
Result (Micro-benchmark)



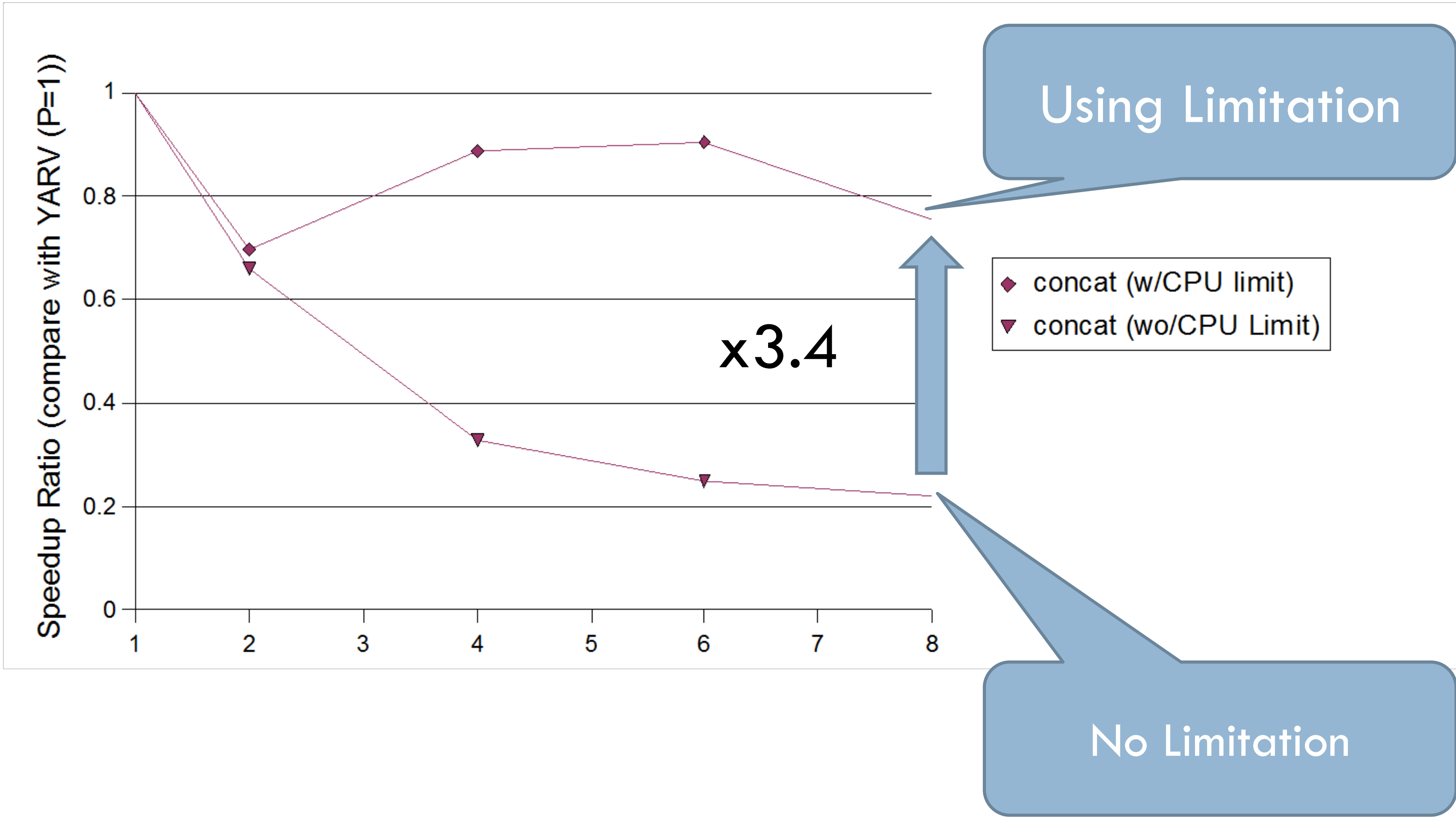
- •fib: fib(N) (Make new Thread if N>30)
- •hetero: fib + concat (1 thread)
- •mandel: Mandelbrot (Big GC overhead)
- •concat: String Concatenate (No Parallelism)

Evaluation Result (Micro-benchmark)



x 7.4
w/8 Cores

CPU Limitation



Using Limitation

x3.4

No Limitation

Parallel Thread Execution Problem

- Unsafe “Old C” methods
  - Replacing all is not easy task
  - Man Power Problem?
- Programming Model
  - Is Parallel Thread Application easy to write?
- Ruby 1.9
  - 1.9 support Native Thread
  - 1.9 doesn’t support Parallel Thread Execution

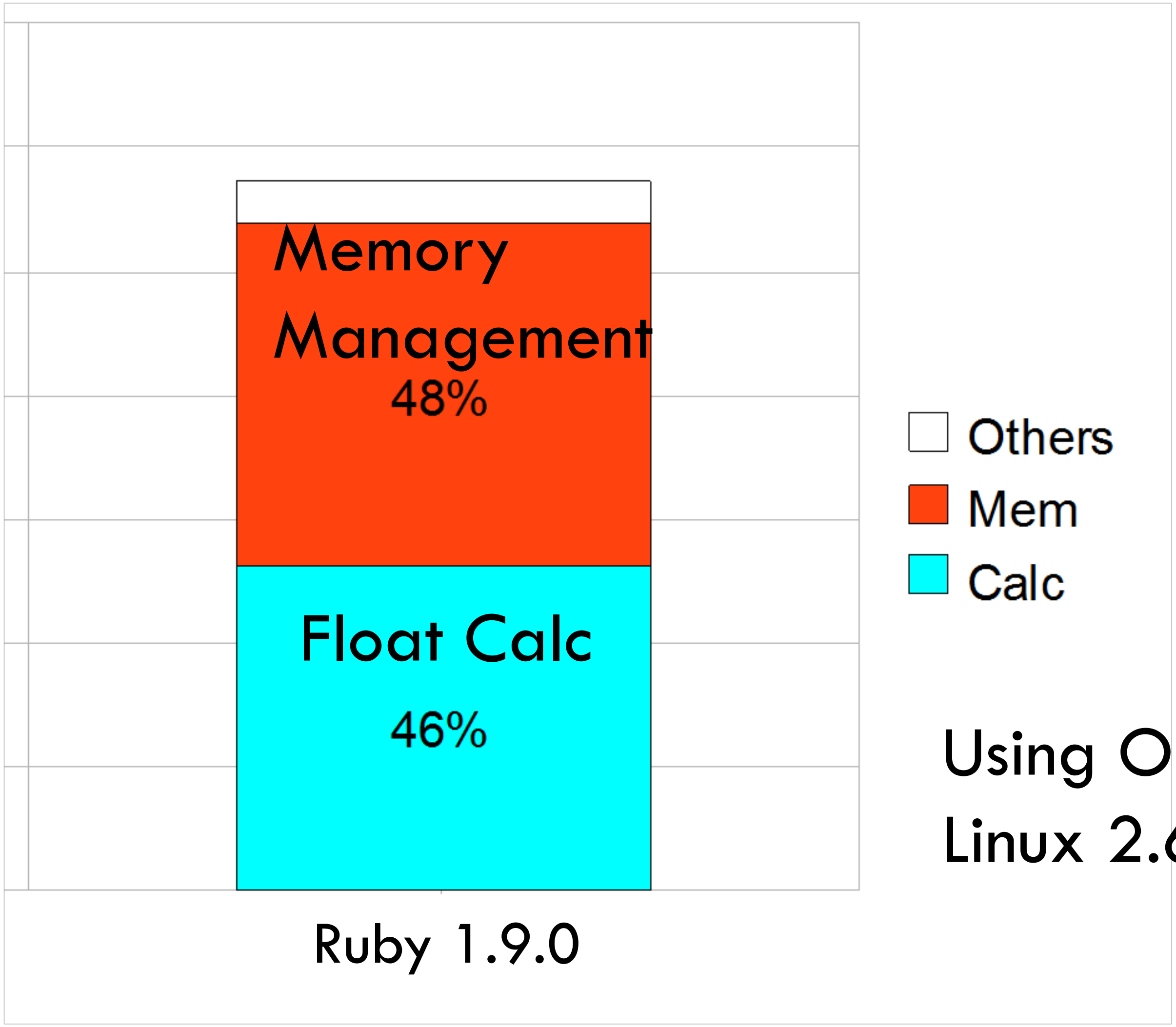
Embedded Float Representation

- Float object is not immediate type
  - This means that Float is “allocated” each time
  - Ex) Fixnum, Symbol, etc
- Half execution time of Float calculation is Memory management

Toy-Program

```
i = 0; f = 0.0
while i<30_000_000
  i += 1
  f += 0.1; f -= 0.1
  f += 0.1; f -= 0.1
  f += 0.1; f -= 0.1
  f += 0.1; f -= 0.1
end
```

List of Execution Time Toy-Program



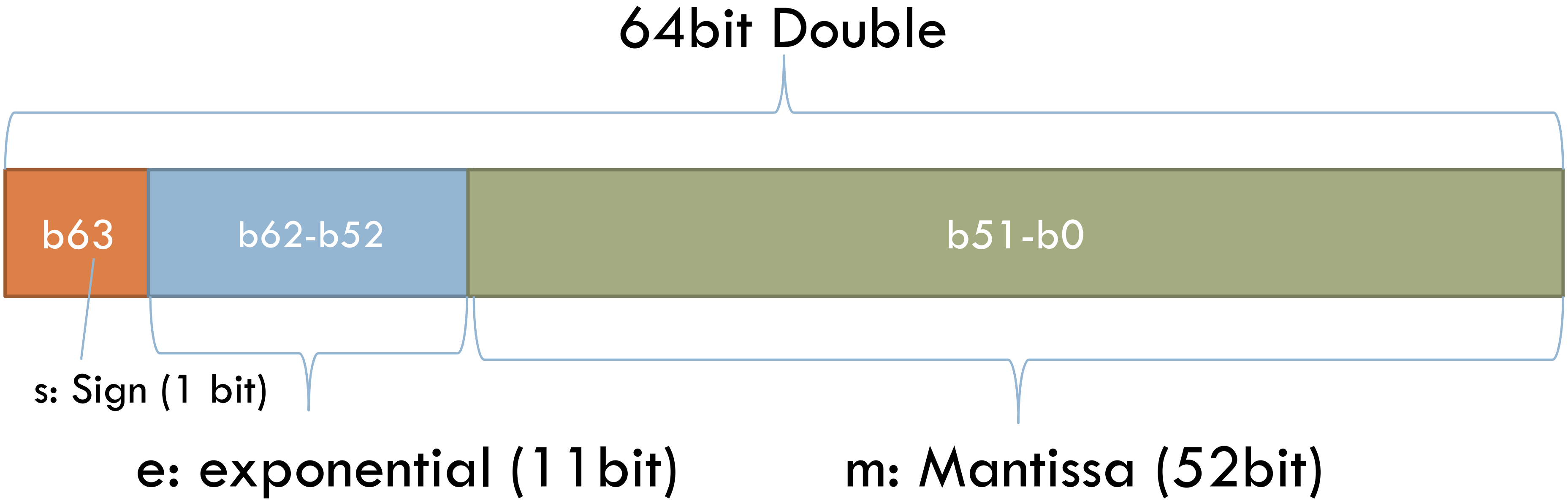
Using OProfile

Linux 2.6 (x86_64), Xeon

Embed Float Object as Fixnum

- Solution: Embed 64bit Float value to 64bit CPU Pointer type!

Review
IEEE 754 Double Precision Representation



$$-1^s 2^{e-1024} m \quad (m = 1 + \sum_{i=0}^{51} \frac{b_i}{2^{52-i}})$$

Discussion
How to Embed 64 bit Double?

- VALUE embed Object doesn't need memory overhead
- **64bit CPU have 64 bit pointer type**
  → Use 64 bit CPU
- At least we need 1 bit for TAG bit
  - From Mantissa?
    - Decrease Precision
  - From Exponential?
    - Decrease Representation Range

Proposal

- From Exponential

  But Store Float in Heap if it is Out of Range

  → **Save a Range and Precision**

  - Often used 01000000000b～10111111111b

    (2^{-512}~2^{511})

  - If Float is out of range, alloc from Heap
  - **Float Out of this Range is Rare Number on Numeric Application -> Practical Solution**

Proposal
Real Program

□ 1) Check the Range of “e” (512～1535)

□ 2) IEEE745 double -> Float (Encoding)

□ 3) Float -> IEEE745 double (Decoding)

Henry S. Warren, Jr. Hacker's Delight
ハッカーのたのしみ
本物のプログラマはいかにして問題を解くか
ヘンリー・S・ウォーレン, ジュニア

Proposal
Float Representation with Tag

- e: 10000000000b〜01111111111b
- Note that if “b62 != b61”, we can embed.
- On Ruby, Tag is at LSB

  → Left Rotate **3bit**
- b63 b62 b61 b60 ··· b0 → 3 bit rotate

  b60 ··· b0 b63 b62 b61

Proposal
Real Encoding Code

```
VALUE rb_float_new(double dbl) {
  VALUE v1 = BIT_DOUBLE2VALUE(dbl);
  VALUE v2 = BIT_ROTL(v1, 3);
  if ((v2 + 1) & 0x02) // check lower 2 bits
    return v2 | 0x01;     // Embed tag
  else {
    if (dbl == 0) // 0.0
      return ruby_float_zero;
    else                  // alloc from Heap
      return rb_float_new_in_heap(dbl);
  }}
```

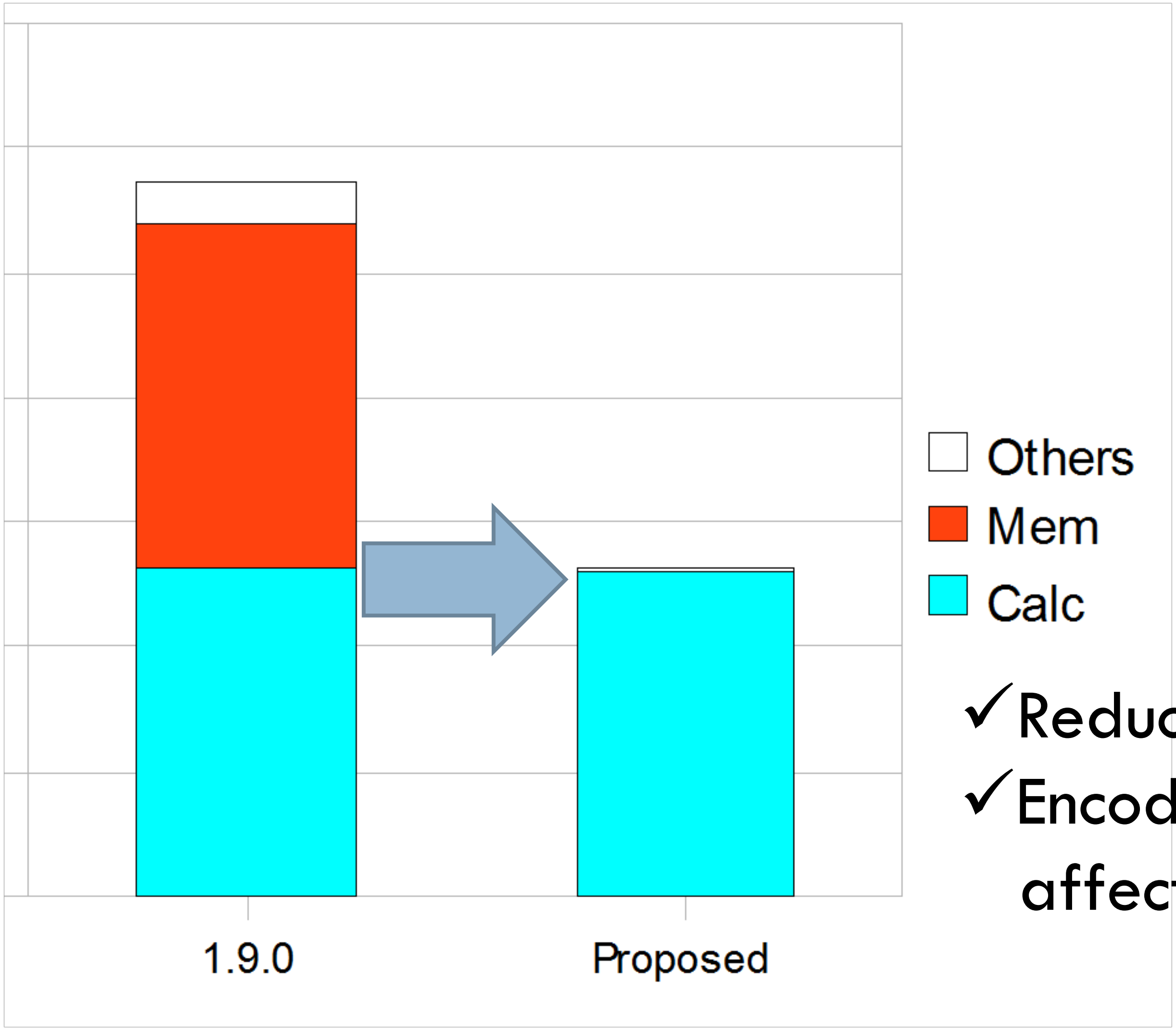
Proposal
Real Decode Code

```
double RFLOAT_VALUE(VALUE v) {
  if (v & 1) {
    VALUE v1 = v ^ ((v >> 1) & 1);
    VALUE v2 = BIT_ROTR(v1, 3);
    return BIT_VALUE2DOUBLE(v2);
  }
  else
    return RFLOAT(v)->float_value;
}
```

Implementation

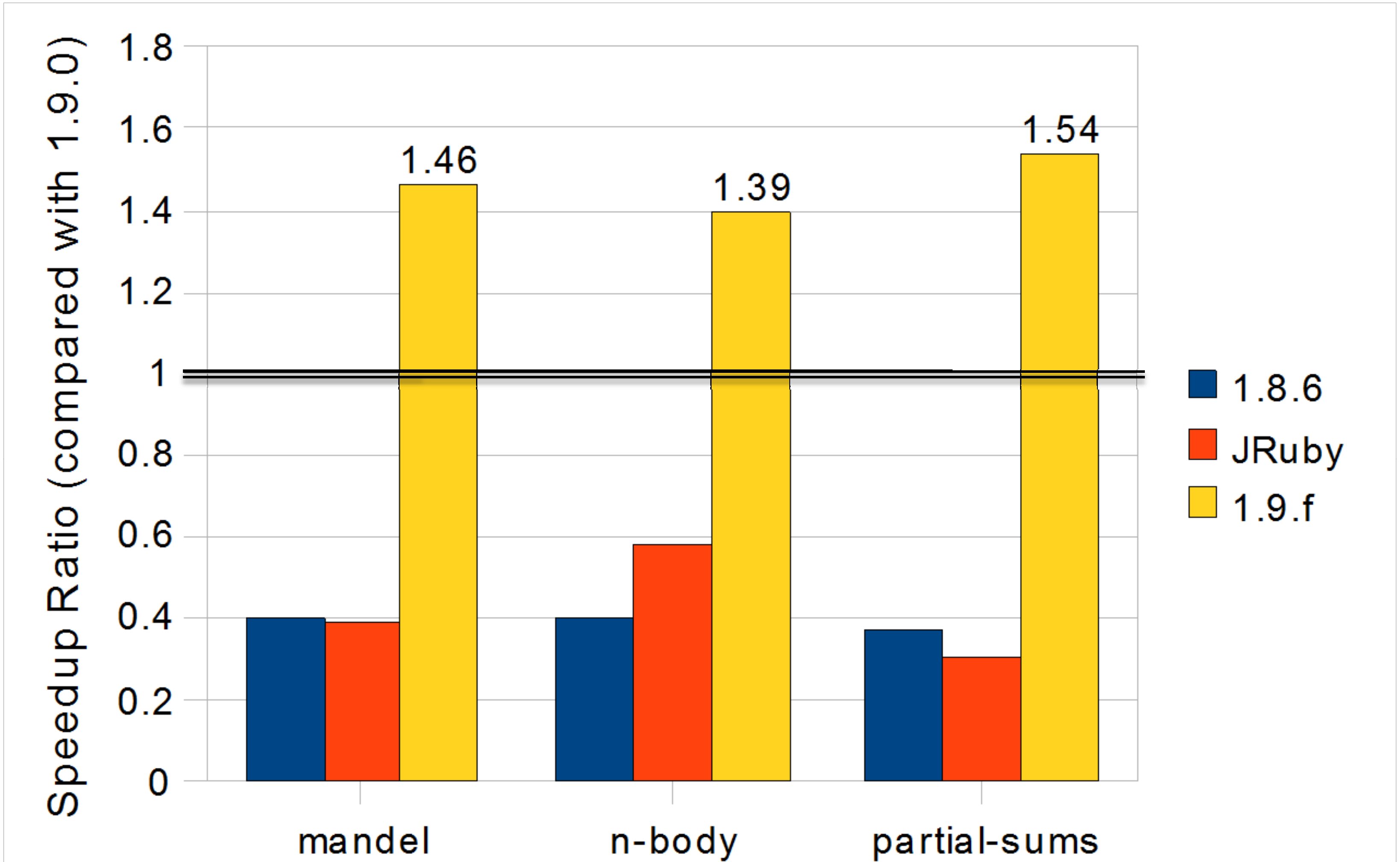
- Ruby 1.9.0-0
- Easy to Implementation
- No Spec Changes

Evaluation
Toy-Program



✓Reduce Mem Time
✓Encode/Decode don't affect to Performance

Evaluation
Compared with other Ruby Impl.



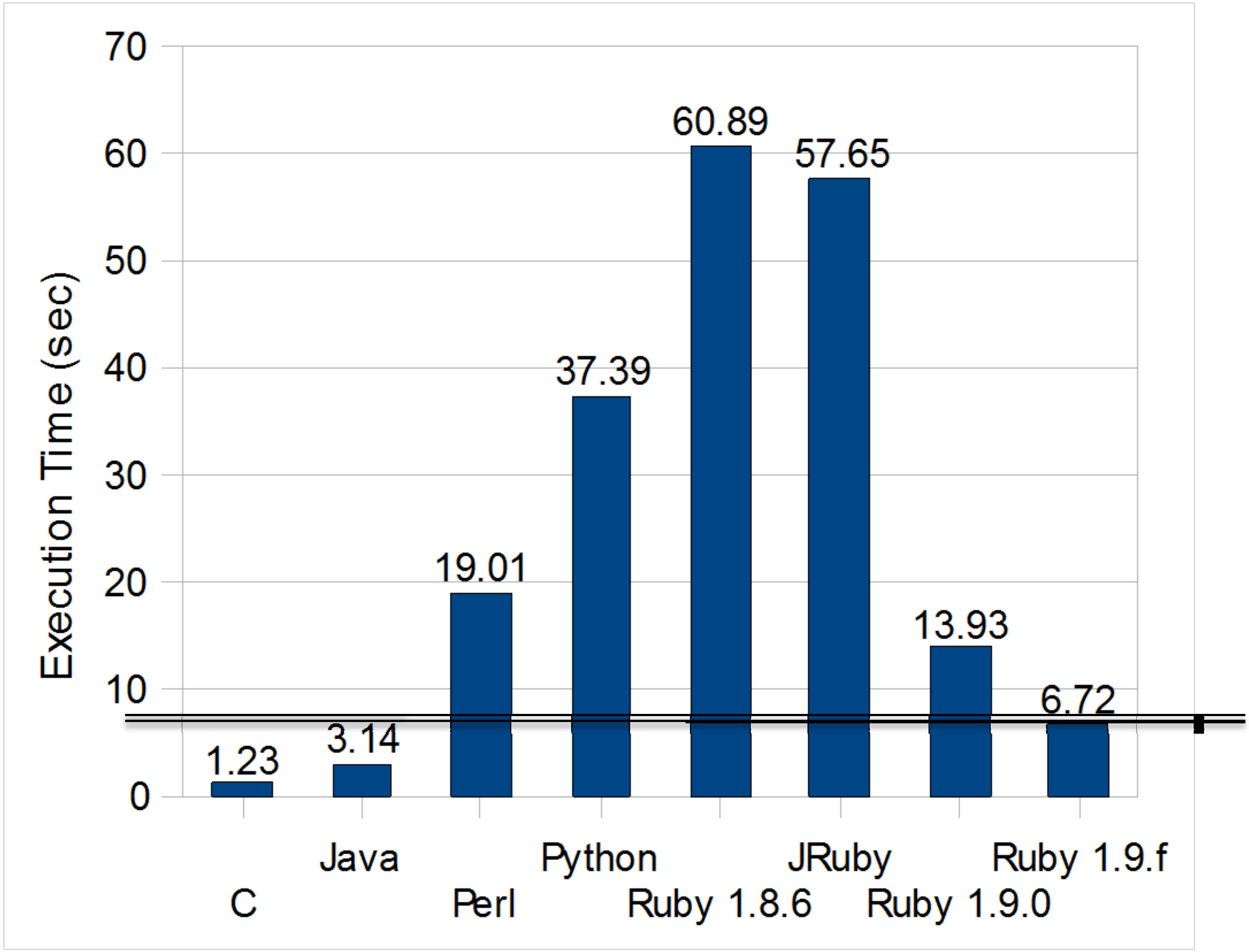
From Comp. Lang. Shootout [4]

Evaluation
Compared with Other Languages

- Evaluate with other languages
- Note that C/Java use “volatile” to avoid optimization

```
i = 0; f = 0.0
while i<30_000_000
   i += 1
    f += 0.1; f -= 0.1
    f += 0.1; f -= 0.1
    f += 0.1; f -= 0.1
    f += 0.1; f -= 0.1
end
```

Evaluation
Compared with Other Languages



[PLAN] JIT Compiler

- I’m re-designing to reduce VM instructions to impl. it easy
  - Current VM has about 50 instructions
  - Ex) “definemethod” move to “Method”

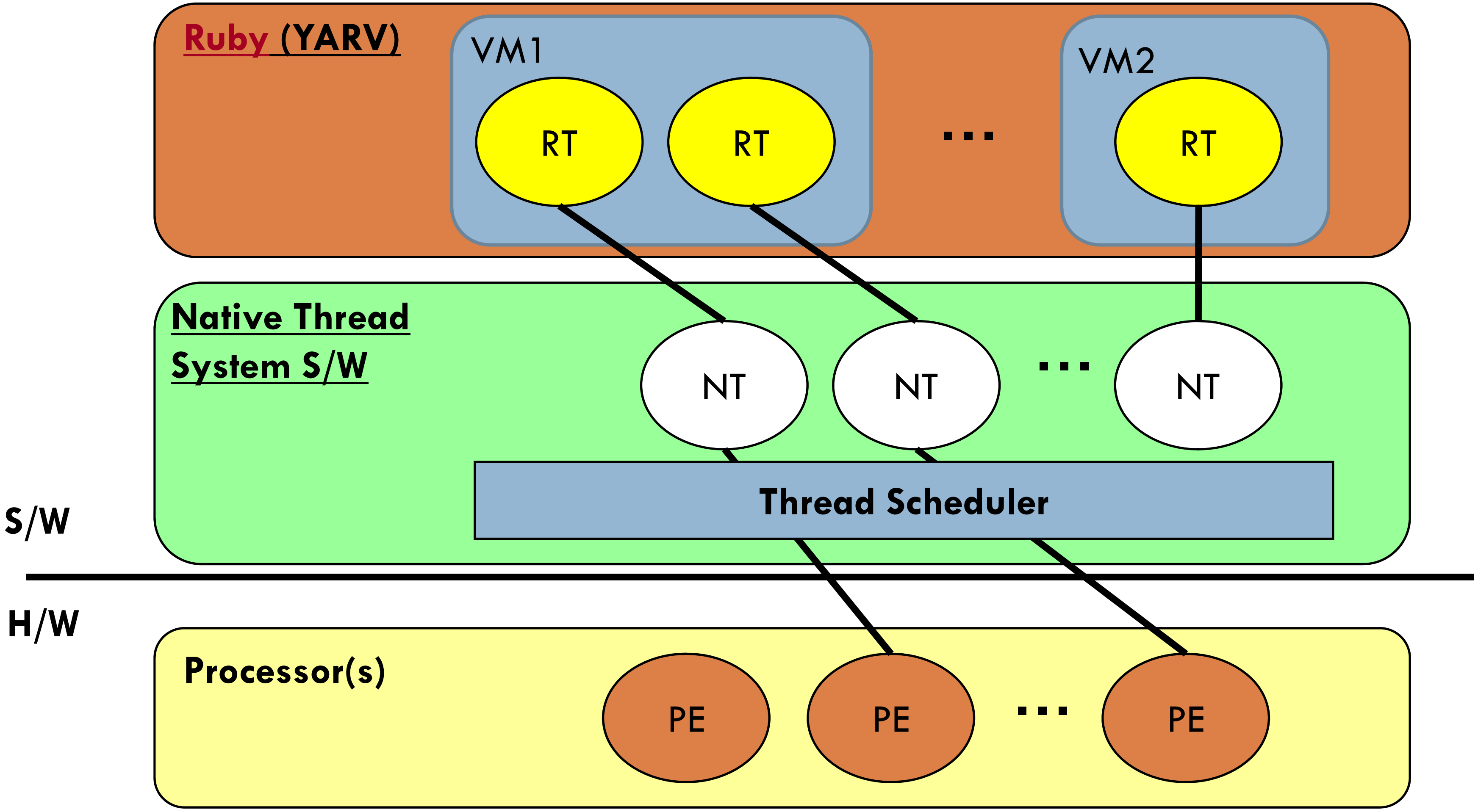
[PLAN]
Pre-Compiler

- YARV VM Generator helps us
  - Ruby to “Pre-compiled”
  - Ruby to “C”
- Purpose
  - Eliminate Loading-Time
  - More aggressive optimization
  - Obfuscation (?)

[PLAN]
Multi-VM Creation

- Purpose
  - Embed Ruby into Application
    - mod_ruby, …
  - Sand-box

Multi-VM Overview



PE: Processor Element, UL: User Level, KL: Kernel Level

Multi-VM Points

- How to control VMs?
  - C Level? → Designed with Nobuyoshi Nakada
    - Making new VM is need only 3 lines
  - Ruby Level?
- How to share environments Inter VM
  - Trade off between Isolation and Util.

[PLAN] Customizable VM Core

- Ruby is tooooo FAT to use XXX purpose
  - Many Many Convenience Methods/Feature
- Need Re-design Ruby Core

[PLAN] Debug/Profile Support Feature

- Only cheep Debugger/Profiler API
  - set_trace_func, Thread#set_trace_func
- Introduce "break" instruction?

Future Work
Benchmark

- Current Benchmark suits is for checking YARV Performance
  - Focus to YARV optimization
  - Toy benchmarks
- We need more pragmatic benchmarks

Summary

- YARV Merged into Ruby 1.9
- I’m working at Advanced VM Topics
  - Performance
    - Parallel Thread Execution
    - Embedding Float Value
    - JIT Compiler
    - Pre-Compiler
      - “Ruby to Compiled file” Compiler
      - “Ruby to C” Compiler
  - New Feature
    - Multi-VM Creation
    - Customizable Ruby Core
    - Debug/Profile support feature

Summary

Merging YARV is not a goal, but a start

VM is a very flexible infrastructure to hack

One more thing…

Sasada Lab@U-Tokyo

- I’ll make a laboratory from 2009, Apr
  - Department of Creative Informatics, Graduate School of Information Science and Technology, The University of Tokyo
  - Graduate School
  - Lab is at Akihabara, Tokyo, Japan
- Unfortunately I can’t employ you as Research Assistant
  - There are not enough grants in Japan…

Research Topics

- Ruby, Ruby, Ruby, PHP, Ruby, Ruby
- Ruby, Ruby, Ruby, Ruby, Python, Ruby
- Ruby, Perl, Ruby, Ruby, Ruby, Ruby
- Ruby, Ruby, Ruby, Ruby, Lua, Ruby
- Ruby, Ruby, Java, Ruby, Ruby, Ruby
- Implementation of Programming Language
- Operating System / Processor Architecture
- Software development

Sasada Lab.

□

```
if you.have_interest(
  :Japan, Tokyo, :Akihabara,
  :Japanese,
  :Ruby, :Research, :Development
)
  you.send_mail_to “ko1 at atdot dot net”
end
```

Thank you for your attention!
Any Questions?

ささだ こういち
Koichi Sasada
Ko1 at atdot dot net