Compiling and Optimizing Scripting Languages

Paul Biggar and David Gregg

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Google, 18th March, 2009

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1. dont have to obduscate your code for performance

Motivation

- User needs web page in 0.5 seconds
  - Execution time
  - DB access
  - Network latency
  - Browser rendering
- Easier maintainance
- What if execution was:
  - 2x as fast?
  - 10x as fast?

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Outline

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1. Introduction to phc
2. Current state of phc
   - Challenges to compilation?
   - phc solution: use the C API
   - Speedup
3. Next for phc - Analysis and Optimization
   - Simple Optimizations
   - Advanced Optimizations
4. Experiences with PHP

Outline

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1. BSD licence useful since its easy to extend
2. Well engineered - turns out you dont get a phd for that

phc

- http://phpcompiler.org
- Ahead-of-time compiler for PHP
- Edsko de Vries, John Gilbert, Paul Biggar
- BSD license
- Latest release: 0.2.0.3 - compiles non-OO
- svn trunk: compiles most OO

phc

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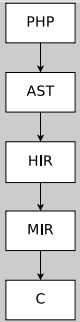
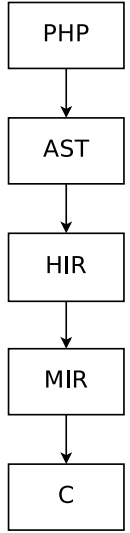
1. All can be unparsed to PHP

Structure of **phc**



Structure of **phc**



PHP

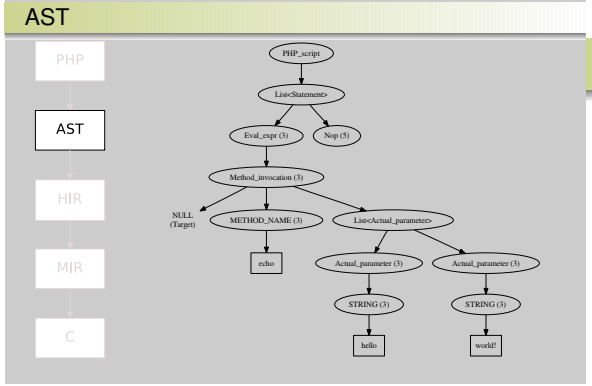

```
<?php

  echo "hello", "world!";

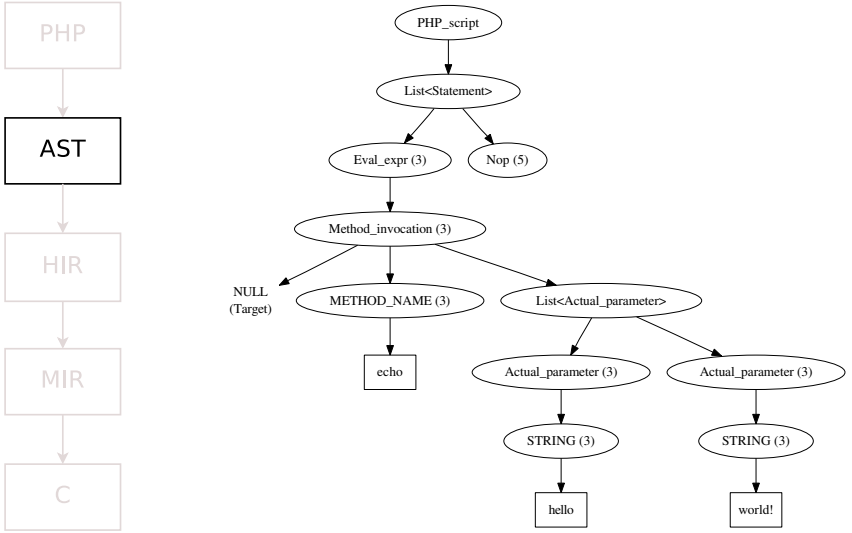
?>
```

1. better than parse (“concrete syntax”) tree

AST

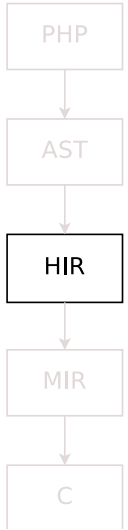


AST



1. 3AC
2. Still PHP

HIR




```
<?php
  $x = $a + $b + $c + $d;
?>
```

```
<?php
  $TLE0 = ($a + $b);
  $TLE1 = ($TLE0 + $c);
  $x = ($TLE1 + $d);
?>
```

1. Not PHP
2. Gotos

MIR


```
<?php
  while ($cond)
    echo "hello", "world!";
?>

<?php
L7:
  $TLE0 = !$cond;
  if ($TLE0) goto L3 else goto L6;
L6:
  print('hello');
  print('world!');
  goto L7;
L3:
?>
```

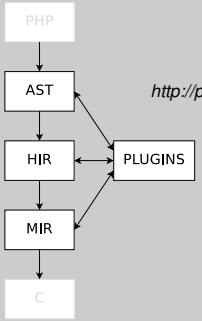
MIR


```
<?php
  while ($cond)
    echo "hello", "world!";
?>

<?php
L7:
  $TLE0 = !$cond;
  if ($TLE0) goto L3 else goto L6;
L6:
  print('hello');
  print('world!');
  goto L7;
L3:
?>
```

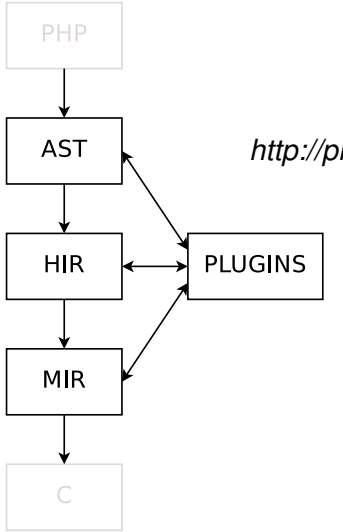
1. Visitor pattern
2. We use it for testing a lot
3. Manual documents it well
4.

Plugins



http://phpcompiler.org/doc/latest/devmanual.html

Plugins



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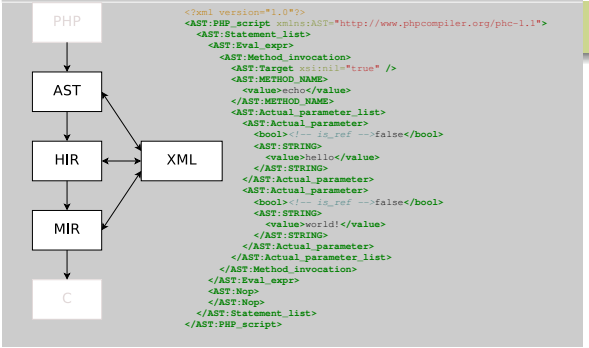
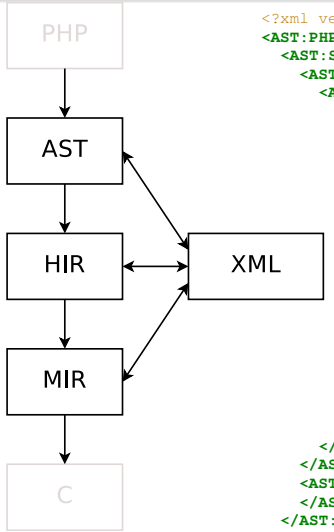
XML



XML




```
<?xml version="1.0"?>
<AST:PHP_script xmlns:AST="http://www.phpcompiler.org/phc-1.1">
  <AST:Statement_list>
    <AST:Eval_expr>
      <AST:Method_invocation>
        <AST:Target xsi:nil="true" />
        <AST:METHOD_NAME>
          <value>echo</value>
        </AST:METHOD_NAME>
        <AST:Actual_parameter_list>
          <AST:Actual_parameter>
            <bool><!-- is_ref -->false</bool>
            <AST:STRING>
              <value>hello</value>
            </AST:STRING>
          </AST:Actual_parameter>
          <AST:Actual_parameter>
            <bool><!-- is_ref -->false</bool>
            <AST:STRING>
              <value>world!</value>
            </AST:STRING>
          </AST:Actual_parameter>
        </AST:Actual_parameter_list>
      </AST:Method_invocation>
    </AST:Eval_expr>
    <AST:Nop>
    </AST:Nop>
  </AST:Statement_list>
</AST:PHP_script>
```

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1. Correctness
2. Large libraries
3. Odd features
4. No spec

A Practical Solution for Scripting Language Compilers

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ACM Symposium on Applied Computing - PL track
12th March, 2009

SAC 2009

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Sneak peak

- Problem: Scripting languages present “unique” problems (in practice)
- Solution: Re-use as much of the ~~*Canonical*~~ *Reference Implementation* as possible.

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Undefined

The PHP group claim that they have the final say in the specification of PHP. This group's specification is an implementation, and there is no prose specification or agreed validation suite. There are alternate implementations [...] that claim to be compatible (they don't say what this means) with some version of PHP.

D. M. Jones. Forms of language specification: Examples from commonly used computer languages. ISO/IEC JTC1/SC22/OWG/N0121, February 2008.

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1. all written in C, not PHP
2. Mike Furr earlier: 1000 methods/classes in C
3. 4870 functions, 1000 methods

Batteries included

Jeff Atwood, Coding Horror, May 20th, 2008
http://www.codinghorror.com/blog/archives/001119.html

Batteries included

```
abs()                           apc_load_constants()            array_intersect()               array_values()
acos()                          apc_sma_info()                  array_intersect_assoc()         array_walk()
acosh()                         apc_store()                     array_intersect_key()           array_walk_recursive()
addcslashes()                   apd_breakpoint()                array_intersect_uassoc()        ArrayIterator::current()
addslashes()                    apd_callstack()                 array_intersect_ukey()          ArrayIterator::key()
aggregate()                     apd_clunk()                     array_key_exists()              ArrayIterator::next()
aggregate_info()                apd_continue()                  array_keys()                    ArrayIterator::rewind()
aggregate_methods()             apd_croak()                     array_map()                     ArrayIterator::seek()
aggregate_methods_by_list()     apd_dump_function_table()       array_merge()                   ArrayIterator::valid()
aggregate_methods_by_regexp()   apd_dump_persistent_resources() array_merge_recursive()         ArrayObject::__construct()
aggregate_properties()          apd_dump_regular_resources()    array_multisort()               ArrayObject::append()
aggregate_properties_by_list()  apd_echo()                      array_pad()                     ArrayObject::count()
aggregate_properties_by_regexp() apd_get_active_symbols()       array_pop()                     ArrayObject::getIterator()
aggregation_info()              apd_set_pprof_trace()           array_product()                 ArrayObject::offsetExists()
apache_child_terminate()        apd_set_session()               array_push()                    ArrayObject::offsetGet()
apache_get_modules()            apd_set_session_trace()         array_rand()                    ArrayObject::offsetSet()
apache_get_version()            apd_set_socket_session_trace()  array_reduce()                  ArrayObject::offsetUnset()
apache_getenv()                 array()                         array_reverse()                 arsort()
apache_lookup_uri()             array_change_key_case()         array_search()                  ascii2ebcdic()
apache_note()                   array_chunk()                   array_shift()                   asin()
apache_request_headers()        array_combine()                 array_slice()                   asinh()
apache_reset_timeout()          array_count_values()            array_splice()                  asort()
apache_response_headers()       array_diff()                    array_sum()                     aspell_check()
apache_setenv()                 array_diff_assoc()              array_udiff()                   aspell_check_raw()
apc_add()                       array_diff_key()                array_udiff_assoc()             aspell_new()
apc_cache_info()                array_diff_uassoc()             array_udiff_uassoc()            aspell_suggest()
apc_clear_cache()               array_diff_ukey()               array_uintersect()              assert()
apc_compile_file()              array_fill()                    array_uintersect_assoc()        assert_options()
apc_define_constants()          array_fill_keys()               array_uintersect_uassoc()       atan()
apc_delete()                    array_filter()                  array_unique()                  atan2()
apc_fetch()                     array_flip()                    array_unshift()                 atanh()
```

Jeff Atwood, Coding Horror, May 20th, 2008
http://www.codinghorror.com/blog/archives/001119.html

Change between releases

```
<?php
  var_dump (0x9fa0ff0b);
?>
```

PHP 5.2.1 (32-bit)

int(2147483647)

PHP 5.2.3 (32-bit)

float(2678128395)

Change between releases

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<?php
  var_dump (0x9fa0ff0b);
?>
```

PHP 5.2.1 (32-bit)

int(2147483647)

PHP 5.2.3 (32-bit)

float(2678128395)

1. scripting langs are typically made for interpreters
2. can do source inclusion at compile time
3. same mechanism for plugins

Run-time code generation

```php
<?php
  eval ($argv[1]);
?>
```

```php
<?php
  include ("mylib.php");
  ...
  include ("plugin.php");
  ...
?>
```

Run-time code generation

```php
<?php
  eval ($argv[1]);
?>
```

```php
<?php
  include ("mylib.php");
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```

Outline

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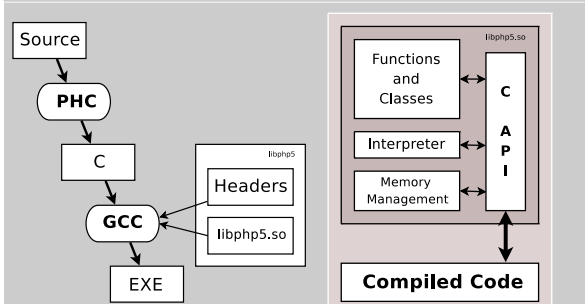
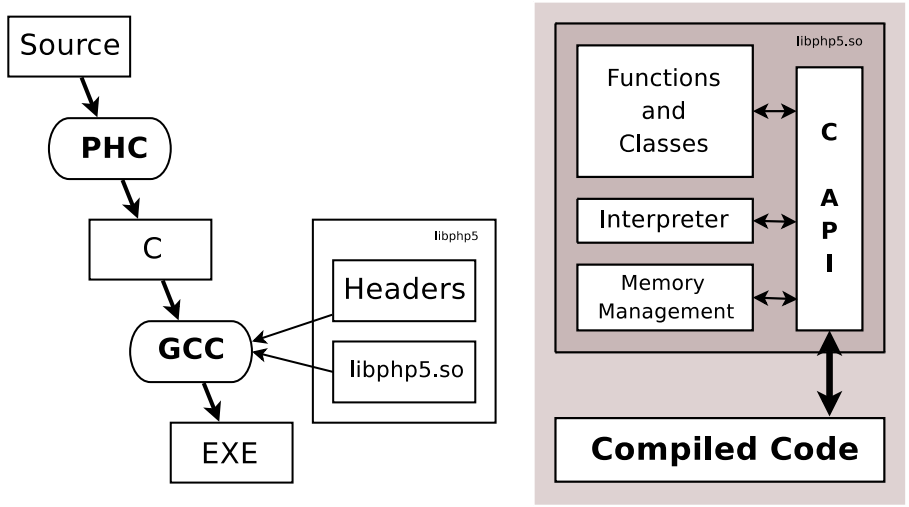
1. RTCG
2. Functions
3. Changes between releases: also use C API at compile-time

Use C API



Use C API



1. C API is just zval + macros and functions
2. Use (target) PHP's C API at run-time

More detail

PHP	zval
Python	PyObject
Ruby	VALUE
Lua	TValue

H. Muhammad and R. Ierusalimschy. C APIs in extension and extensible languages. Journal of Universal Computer Science, 13(6):839–853, 2007.

More detail

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Simple listings: $i = 0

```
// $i = 0;
{
  zval* p_i;
  php_hash_find (LOCAL_ST, "i", 5863374, p_i);
  php_destruct (p_i);
  php_allocate (p_i);
  ZVAL_LONG (*p_i, 0);
}
```

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  php_allocate (p_i);
  ZVAL_LONG (*p_i, 0);
}
```

Example: $i = 0

```
// $i = 0;
{
  if (local_i == NULL)
  {
    local_i = EG (uninitialized_zval_ptr);
    local_i->refcount++;
  }
  zval **p_lhs = &local_i;

  zval *value;
  if ((*p_lhs)->is_ref)
  {
    // Always overwrite the current value
    value = *p_lhs;
    zval_dtor (value);
  }
  else
  {
    ALLOC_INIT_ZVAL (value);
    zval_ptr_dtor (p_lhs);
    *p_lhs = value;
  }

  ZVAL_LONG (value, 0);
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```

Example: $i = $j

```
// $i = $j;
{
  if (local_i == NULL)
  {
    local_i = EG (uninitialized_zval_ptr);
    local_i->refcount++;
  }
  zval **p_lhs = &local_i;

  zval *rhs;
  if (local_j == NULL)
    rhs = EG (uninitialized_zval_ptr);
  else
    rhs = local_j;

  if (*p_lhs != rhs)
  {
    if ((*p_lhs)->is_ref)
    {
      // First, call the destructor to remove any data structures
      // associated with lhs that will now be overwritten
      zval_dtor (*p_lhs);
      // Overwrite LHS
      (*p_lhs)->value = rhs->value;
      (*p_lhs)->type = rhs->type;
      zval_copy_ctor (*p_lhs);
    }
    else
    {
      zval_ptr_dtor (p_lhs);
      if (rhs->is_ref)
      {
        // Take a copy of RHS for LHS
        *p_lhs = zvp_clone_ex (rhs);
      }
      else
      {
        // Share a copy
        rhs->refcount++;
        *p_lhs = rhs;
      }
    }
  }
}
```

Example: $i = $j

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{
  if (local_i == NULL)
  {
    local_i = EG (uninitialized_zval_ptr);
    local_i->refcount++;
  }
  zval **p_lhs = &local_i;

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    }
    else
    {
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      if (rhs->is_ref)
      {
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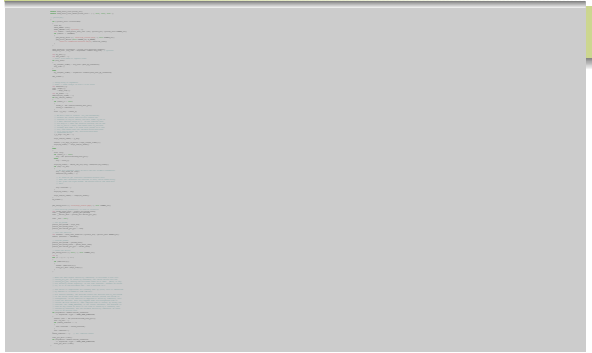
        *p_lhs = rhs;
      }
    }
```

Example: printf ($f)



Example: printf ($f)

Applicability

- Everything
  - Perl
  - PHP
  - Ruby
  - Tcl – *I think*

Applicability

- Everything
  - Perl
  - PHP
  - Ruby
  - Tcl – *I think*

1. Python used to be bad - aycock quote

Applicability

- Everything
  - Perl
  - PHP
  - Ruby
  - Tcl – *I think*
- Except specification
  - Lua
  - Python

Applicability

- Everything
  - Perl
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Applicability

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  - Tcl – *I think*
- Except specification
  - Lua
  - Python
- Not at all
  - Javascript

Applicability

- Everything
  - Perl
  - PHP
  - Ruby
  - Tcl – *I think*
- Except specification
  - Lua
  - Python
- Not at all
  - Javascript

Outline

Outline

1. Why is experiemental evaluation a speedup?
2. That's an interesting result. Shouldnt compilers always be faster!!!
3. PHP's interpreter isnt slowed by interpreter loop. Rather its the level of dynamicism.

Original Speed-up

0.1x
(10 times slower than the PHP interpreter)

Original Speed-up

0.1x
(10 times slower than the PHP interpreter)

1. each statement is pretty high level

The problem with copies

```
<?php
  for ($i = 0; $i < $n; $i++)
    $str = $str . "hello";
?>
```

```
<?php
  for ($i = 0; $i < $n; $i++)
  {
    $T = $str . "hello";
    $str = $T;
  }
?>
```

The problem with copies


```
<?php
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```
<?php
  for ($i = 0; $i < $n; $i++)
  {
    $T = $str . "hello";
    $str = $T;
  }
?>
```

1. We dont need to know how to fold constants - we just pass it off to PHP's eval

Optimization

- Constant folding

```
<?php
  ...
  $T = "5" + true;
  ...
?>
```

```
<?php
  ...
  $T = 6;
  ...
?>
```

Optimization

- Constant folding

```
<?php
  ...
  $T = "5" + true;
  ...
?>
```

```
<?php
  ...
  $T = 6;
  ...
?>
```

Optimization

- Constant folding
- Constant pooling

```
<?php
  $sum = 0;
  for ($i = 0; $i < 10; $i=$i+1)
  {
    $sum .= "hello";
  }
?>
```

Optimization

- Constant folding
- Constant pooling

```
<?php
  $sum = 0;
  for ($i = 0; $i < 10; $i=$i+1)
  {
    $sum .= "hello";
  }
?>
```

1. PHP implements this
2. function cant change afte first invocation - dont need lookup-cache of inline cache or polymorphic inline cache

Optimization

- Constant folding
- Constant pooling
- Function caching

```
// printf ($f);
static php_fcall_info printf_info;
{
  php_fcall_info_init ("printf", &printf_info);

  php_hash_find (
    LOCAL_ST, "f", 5863275, &printf_info.params);

  php_call_function (&printf_info);
}
```

Optimization

- Constant folding
- Constant pooling
- Function caching

```
// printf ($f);
static php_fcall_info printf_info;
{
  php_fcall_info_init ("printf", &printf_info);

  php_hash_find (
    LOCAL_ST, "f", 5863275, &printf_info.params);

  php_call_function (&printf_info);
}
```

Optimization

- Constant folding
- Constant pooling
- Function caching
- Pre-hashing

```
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  zval* p_i;
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Optimization

- Constant folding
- Constant pooling
- Function caching
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Optimization

- Constant folding
- Constant pooling
- Function caching
- Pre-hashing
- Symbol-table removal

```
// $i = 0;
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  php_destruct (local_i);
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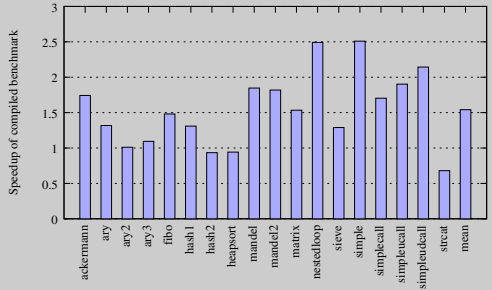
Optimization

- Constant folding
- Constant pooling
- Function caching
- Pre-hashing
- Symbol-table removal

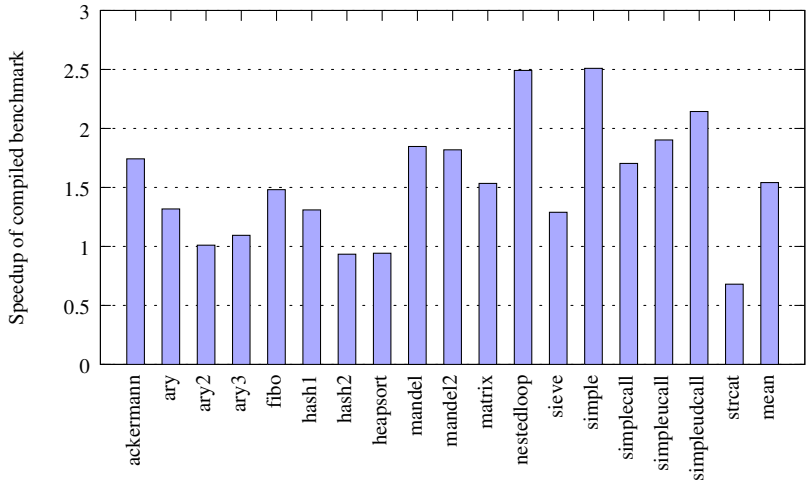
```
// $i = 0;
{
  php_destruct (local_i);
  php_allocate (local_i);
  ZVAL_LONG (*local_i, 0);
}
```

1. Explain how to read graph
2. Much better than 0.1x
3. C compiler: be 5x faster
4. PHP 40x-70x slower

Current speed-up



Current speed-up



Outline

Outline

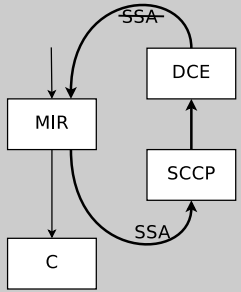
1 Introduction to phc
2 Current state of phc
- Challenges to compilation?
- phc solution: use the C API
- Speedup
3 Next for phc - Analysis and Optimization
- Simple Optimizations
- Advanced Optimizations
4 Experiences with PHP

Outline

Outline

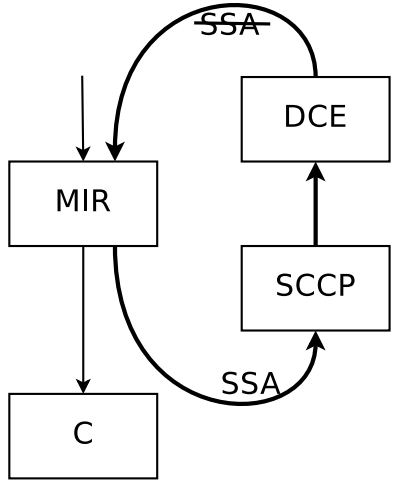
1. 2x speedup

Intra-procedural optimizations



- Dead-code elimination
- Sparse-conditional **constant propagation**

Intra-procedural optimizations



- Dead-code elimination
- Sparse-conditional **constant propagation**

Type-inference

```php
<?php

  function a ($x, $y)
  {
    $str = $x . $y;
    ...
    return $str;
  }

?>
```

Type-inference


```php
<?php

  function a ($x, $y)
  {
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    return $str;
  }

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```

User-space handlers

- __toString
- __get
- __set
- __isset
- __unset
- __sleep
- __wake
- __call
- __callStatic
- ...

User-space handlers

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1. So previous SSA opts were illegal
2. Complete access to interpreter internals
3. Need accurate use-defs

C API handlers

- read_property
- read_dimension
- get
- set
- cast_object
- has_property
- unset_property
- ...

C API handlers

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Unknown types propagate

- local symbol table
- global symbol table
- return values
- reference parameters
- callee parameters

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Analysis design

- Must model types precisely
  - (Possibly unnamed) fields, arrays, variables and method calls

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1. Uses and defintions incomplete - this doesnt use them

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  - Can't use *def-use chains*
  - Can't use *SSA*

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1. Imprecise callgraph - do it lazily

Analysis design

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  - (Possibly unnamed) fields, arrays, variables and method calls
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Algorithm

- Abstract Execution / Interpretation

Algorithm

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1. flow, context, object, field

Algorithm

- Abstract Execution / Interpretation
- Points-to analysis
  - *-sensitive

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Algorithm

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- Points-to analysis
  - *-sensitive
- Constant-propagation
  - Precision
  - Array-indices/field names
  - Implicit conversions

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1. Make polymorphic calls monomorphic
2. Go through each of the problems on the previous slide
3. model types precisely
4. need to model many functions - in contrast to SAC stuff
5. much easier than reimplementing, however

Algorithm

- Abstract Execution / Interpretation
- Points-to analysis
  - *-sensitive
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  - Virtual calls
  - Function annotations

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1. Static-includes optimization needs to be deployment-time
2. hashtables - SAC javascript talk

Complex cases

- Hashtables
- Implicit conversions
- Variable-variables
- $GLOBALS
- Static includes
- $SESSION
- Compiler temporaries

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1. just like hotspot

Interesting thoughts

- Strip off first loop iteration

Interesting thoughts

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1. Would it go well with Gal/Franz tracing?

Interesting thoughts

- Strip off first loop iteration
- JITs or Gal/Franz Tracing?

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1. hope you like PhD work as much as I hope my externs will
2. working with php

Opinions and conjecture

Opinions and conjecture

Opinions and conjecture

1. difficult to get a good mental model, without looking at source - edge cases
2. Then:
3. dont go into it
4. documented all over web

Opinions and conjecture

- Language Problems

Opinions and conjecture

Opinions and conjecture

- Language Problems

1. implementation slow
2. C API prevents fast implementation - tight coupling - unchangable
3. Instead use libs + good FFI + user-code
4. Allows analysis
5. Other implementations
6. Allow experimentation within Zend engine

Opinions and conjecture

- Language Problems
- Implementation problems

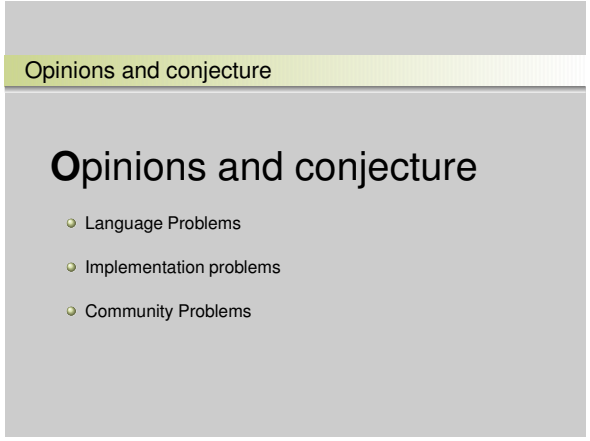
Opinions and conjecture

Opinions and conjecture

- Language Problems
- Implementation problems

1. reference - spending time in GCC world
2. never seen so much bikeshedding
3. needs more code review - possibly even commit-after-review
4. few working on making php “better” - except in APC
5. Alternate implementations/tools not done by community - instead by IBM, roadsend davis, tuwien, stanford, utrecht, trinity. However: YARV,

Opinions and conjecture



Opinions and conjecture

- Language Problems
- Implementation problems
- Community Problems

1. php7k - like py3k
2. break BC
3. remove legacy
4. internally consistent

Fixes

- Remove coupling between libraries and interpreter
- Better community interactions:
  - Pre-commit reviews
  - Mailing list moderation
  - Per-area maintainers
- Love of the language leads to more tools

Opinions and conjecture

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Summary

- Re-use existing run-time for language
- Better yet: standardize libraries (and language?), including FFI
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- Pessimistic assumptions spread
- Language, implementation and community need to be fixed
  - All related?

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Thanks

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- mailing list: `phc-general@phpcompiler.org`
- slides: `http://www.cs.tcd.ie/~pbiggar/`
- contact: `paul.biggar@gmail.com`

Thanks

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