Parrot: VM design gone crackers?

Jonathan Worthington
University Of Cambridge

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What is Parrot?

- A virtual machine for dynamic languages.
- Started out as the Perl 6 internals project – unlike Perl 5, there was to be a clean language/runtime boundary.
- Aims to provide support for many languages and allow interoperability between them.
- Named after an April Fool's joke which referenced a Monty Python sketch. :-)

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Dynamic Languages

- Think Perl[56], Python, Ruby, Tcl…
- Often need their parsers available at runtime
- Classes, methods, functions etc being created at runtime is not unusual
- Much is done symbolically
- Often have language features like continuations, closures, co-routines etc.

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Why a new VM?

- •The JVM and the .NET CLR can handle dynamic languages, but you re-invent quite a few wheels when writing the compiler.
- •Perl 6 should support the range of platforms Perl 5 does – which is a lot. Need something that ports well.
- •A chance to innovate; Parrot never was to be just another JVM clone.

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Parrot Architecture

- A register machine
- Contexts capturing the notion of closures, subroutines/methods and continuations
- Uses continuation passing style
- PMCs: types with a common v-table for interoperability
- Extensible at the instruction and type level
- Many HLL features supported…

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Why virtual register machines?

- VMs have tended to be stack based.
  - Easy to compile to
  - Leads to compact instruction code
  - With a JIT (Just In Time) compiler, you can get very good performance
- However, register architectures have some advantages.

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Why virtual register machines?

- Stack machines have heavy instruction dispatch overhead when interpreting, especially with regard to tweaking the stack pointer.
- Parrot needs to run well on lots of arcane platforms - can't rely on having JIT.
- The cheaper instruction dispatch of register machines is a big advantage.
- Note .NET is slow to interpret – by design.

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Why virtual register machines?

- Another advantage comes when JITing time – you already have register code, possibly that needs no further register allocation; even if it does, still don't need to do stack to register mapping.
- Also, 3-address code more suited to optimization than stack code – don't rely on JIT-time optimizations.
- But what about spilling?

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Variable size register frames

- Originally had a fixed number of registers.
- Intermediate language compiler provides “virtual registers”.
    - Does register allocation
    - Spill to an array
- The register file is just a chunk of memory, so spilling just leads to wasteful memory copying => variable sized register frames.

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Register Frames

- 4 types of registers: Integer, Number, String, PMC.
- Each sub annotated with the number of each that it needs.
- 2 pointers into the register frame allow access to all registers.

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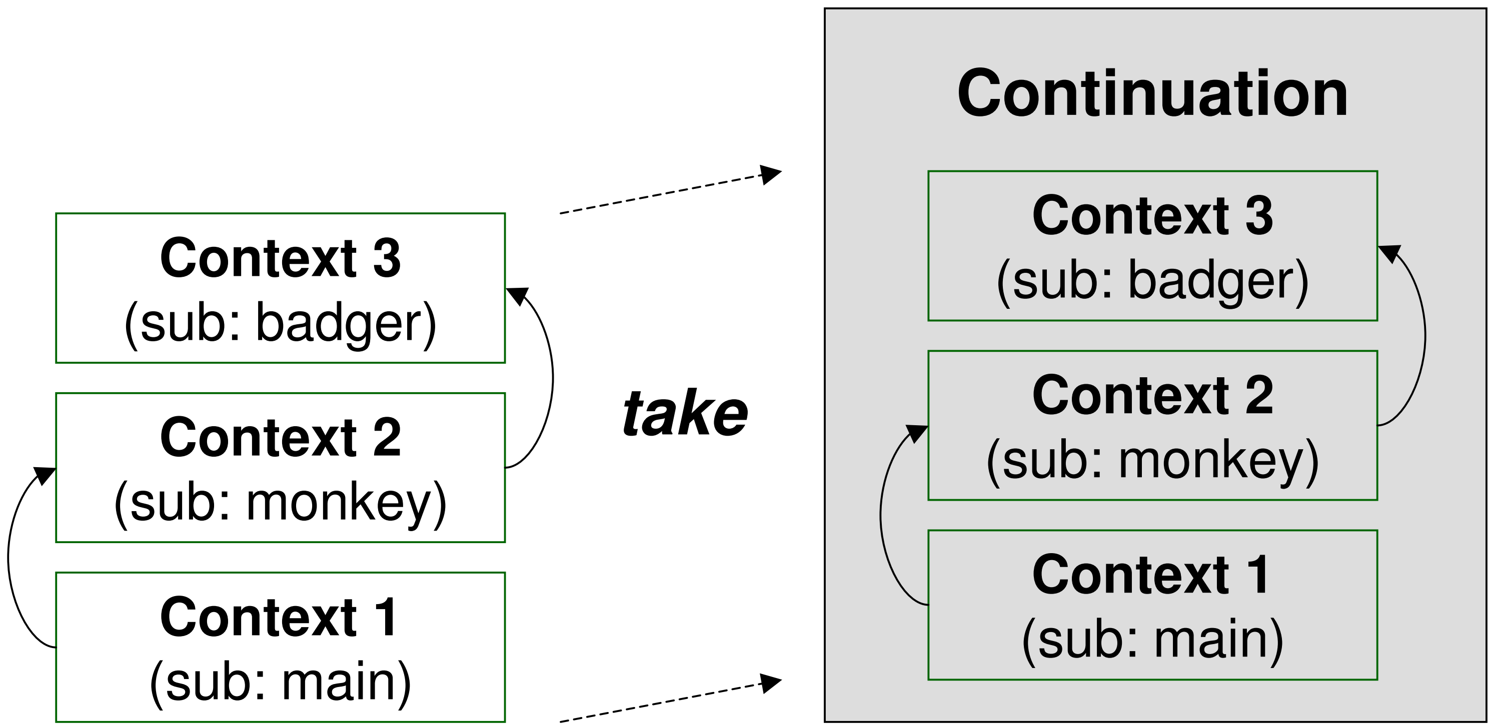
Contexts

- A register frame belongs to a context.
- A context is somewhat analogous to a stack frame – there's one per invocation of a sub and a pointer to the caller's context.
- You also have a context per closure, along with a pointer to its enclosing context.
    - Lexicals are in registers – more later.
- Continuations just a chain of contexts.

Continuation Passing Scheme

•Conceptually, before a call we take a continuation.



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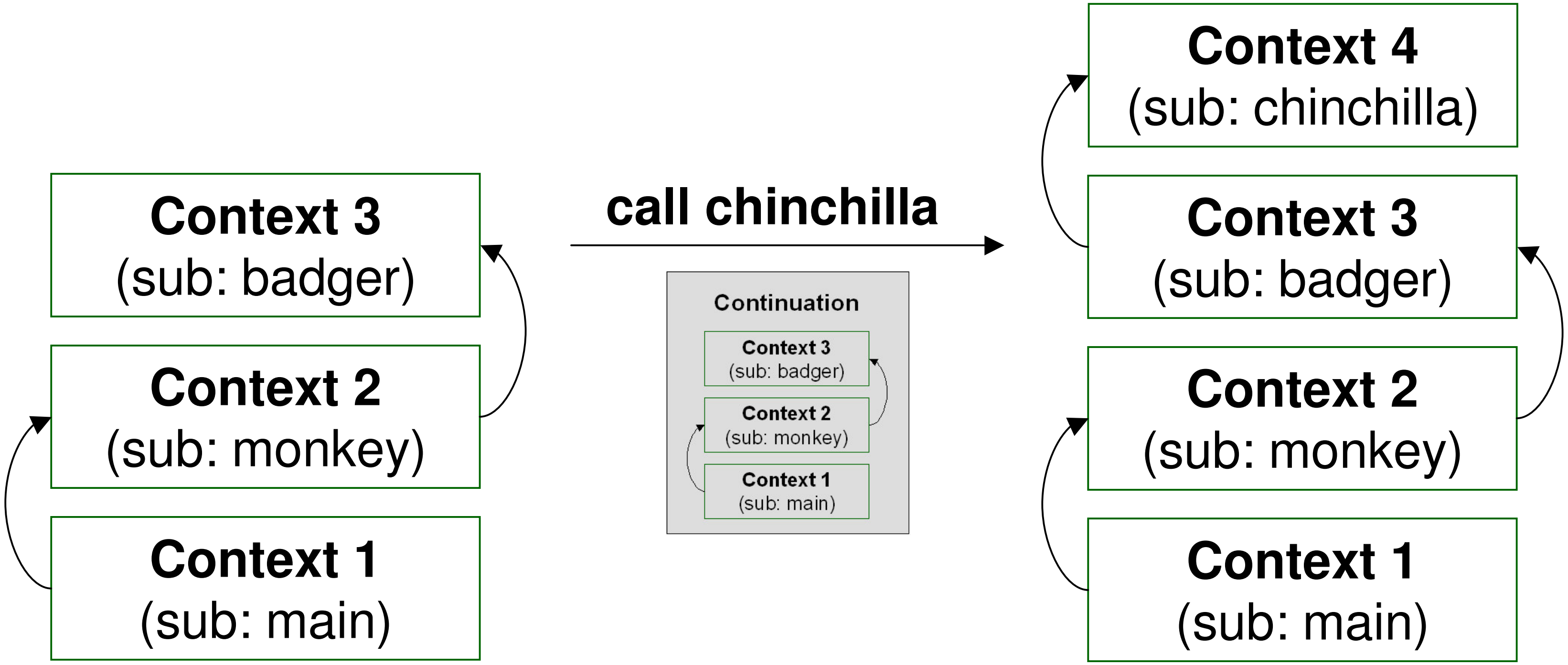
Parrot uses Continuation Passing Scheme

- Then pass the continuation along with the arguments to the sub being called.



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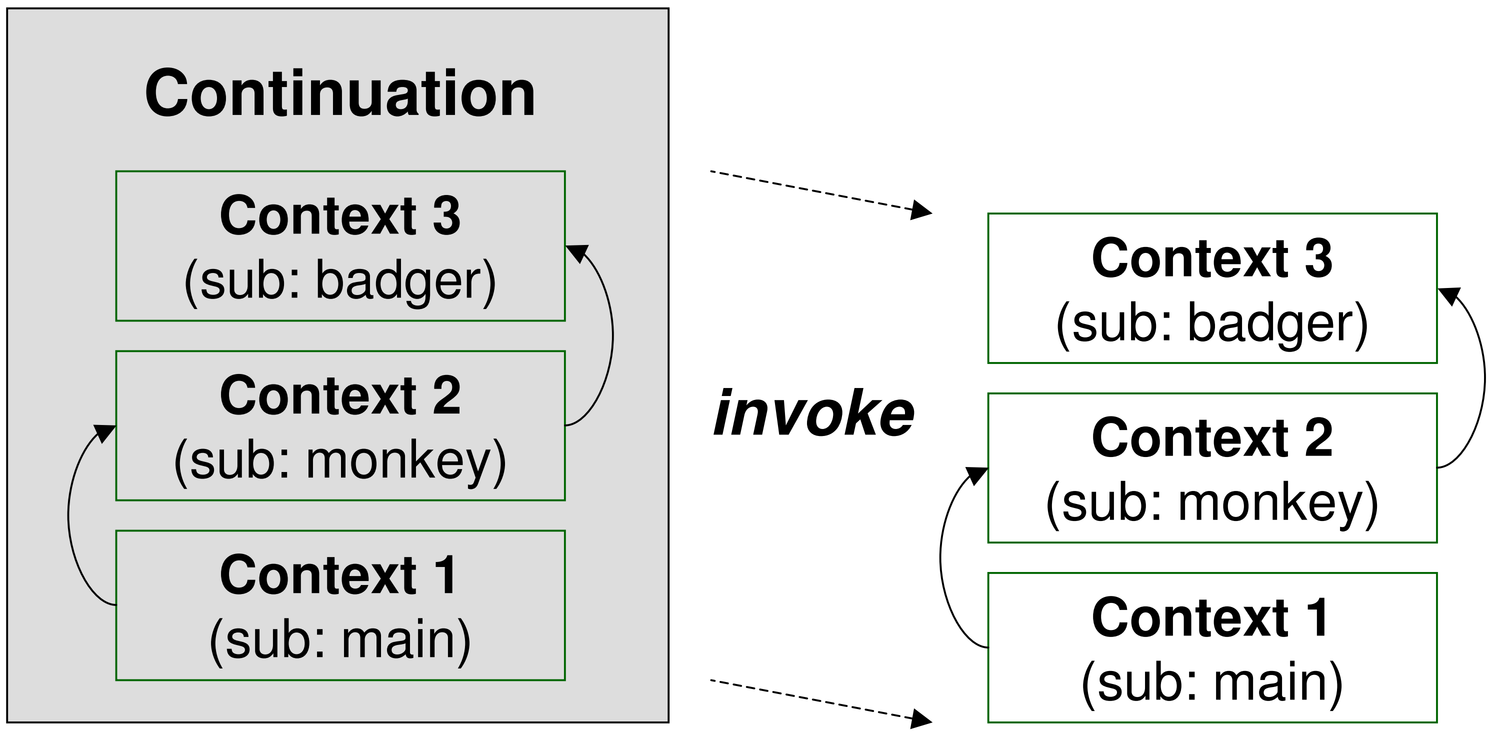
Parrot uses Continuation Passing Scheme

- Invoking a continuation involves replacing the current call chain with what was captured.



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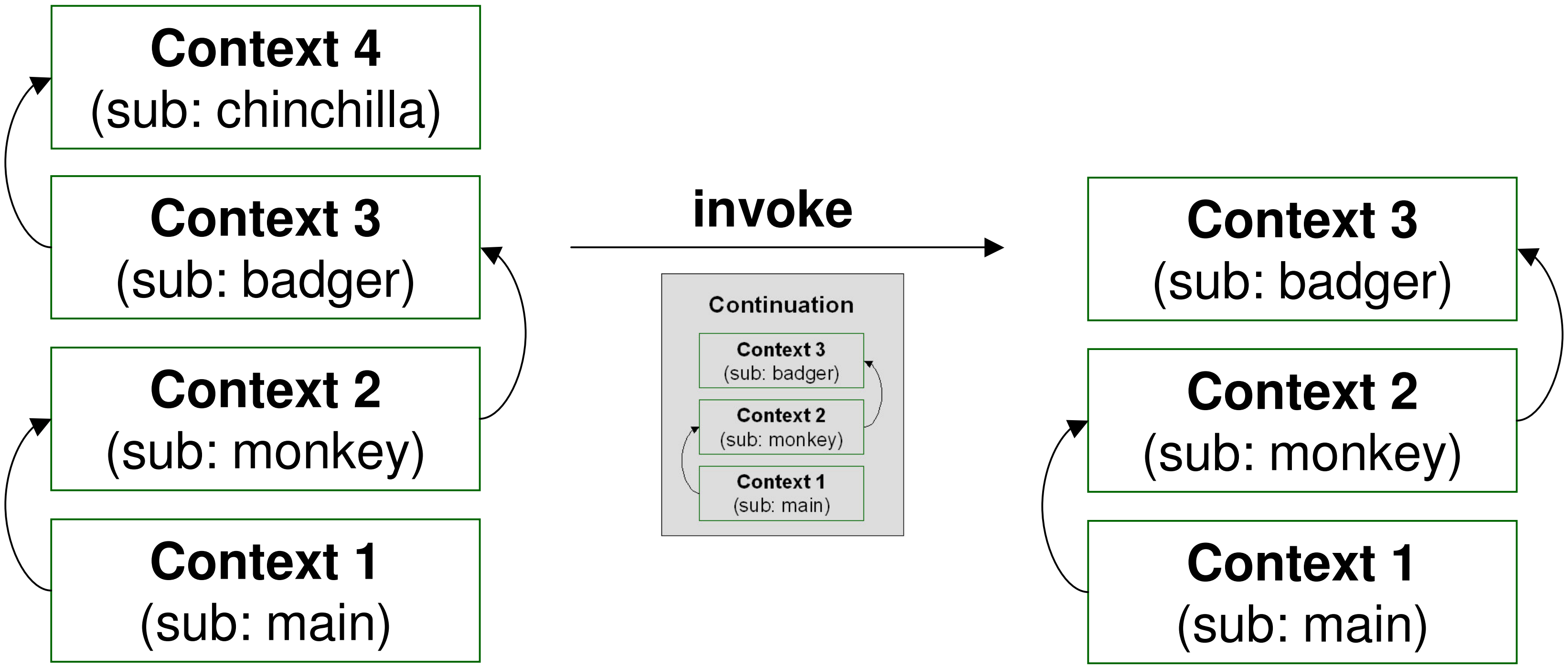
Parrot uses Continuation Passing Scheme

- Conveniently, this turns out to do just what a return would do (noting that a continuation captures the program counter too).



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Why Continuation Passing Scheme?

- Parrot has a lot of context information to save; continuations capture all of it neatly.
- No concerns about over-flowing the stack or over-writing return addresses, so good from a security stand-point.
- Tail calls become cheap to implement – just pass on the already taken continuation.
- Doesn’t this make calling really expensive?

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Return Continuation Optimization

- Don’t really copy all of the contexts.
- Give each context a “valid for re-use” flag.
- If a real continuation is taken, then walk down the contexts chain, marking each one as invalid.
- Also have a reference count on a context for how many continuation are using it, so only need to walk down as far as when the last continuation was taken.

What is a PMC?

- A PMC defines a type with a certain set of behaviours and internal representation.
- Implements some of a pre-defined set of methods that represent behaviours a type may need to customize, such as integer assignment, addition, getting the number of elements, etc.
- Method bodies written in C, but much code is generated by a build tool.

How do PMCs work?

- Each PMC has a pointer to a v-table.
- When operations are performed on PMCs, the v-table is used to call the appropriate PMC method.
- A PMC may inherit from many other PMC types.
- PMCs are eligible for garbage collection – may tell the garbage collector what other PMCs it references too.

How do PMCs work?

inc P3

P0	P1	P2	P3	P4	P5	P6	P7
			Ref				

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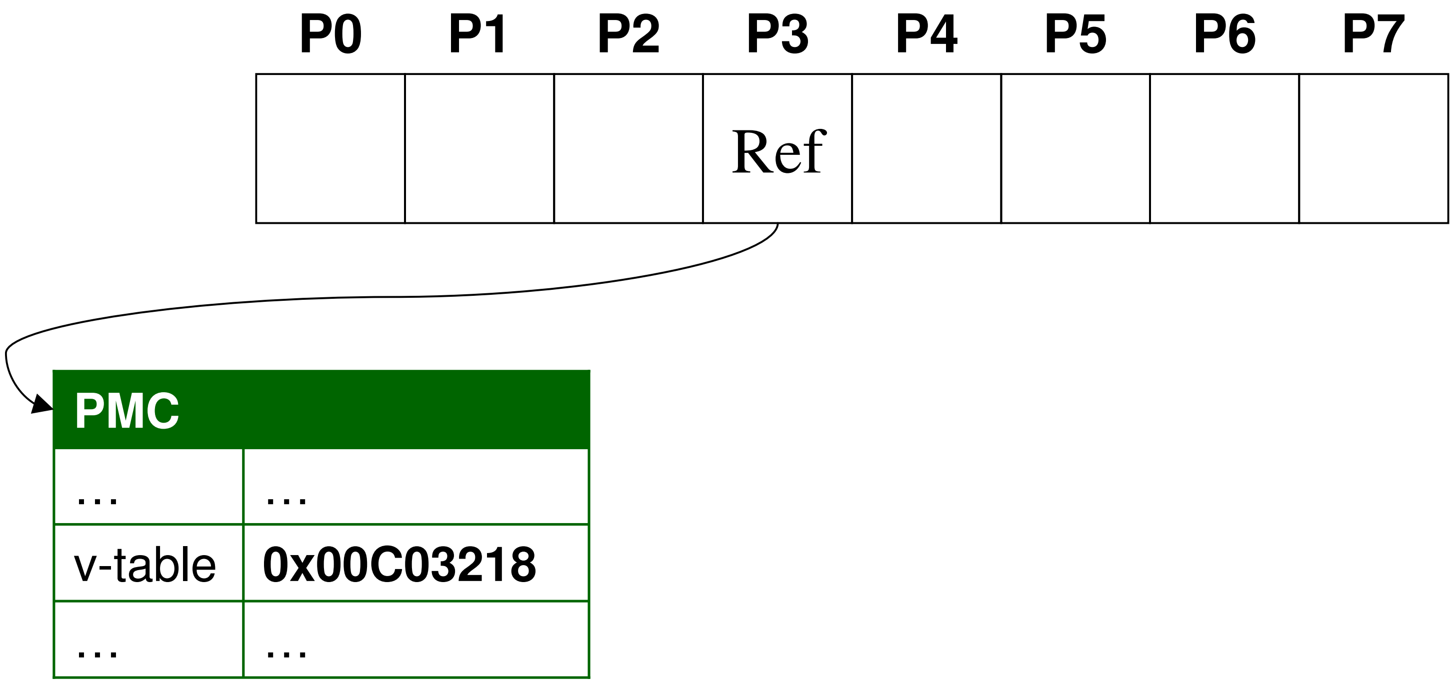
How do PMCs work?

inc P3



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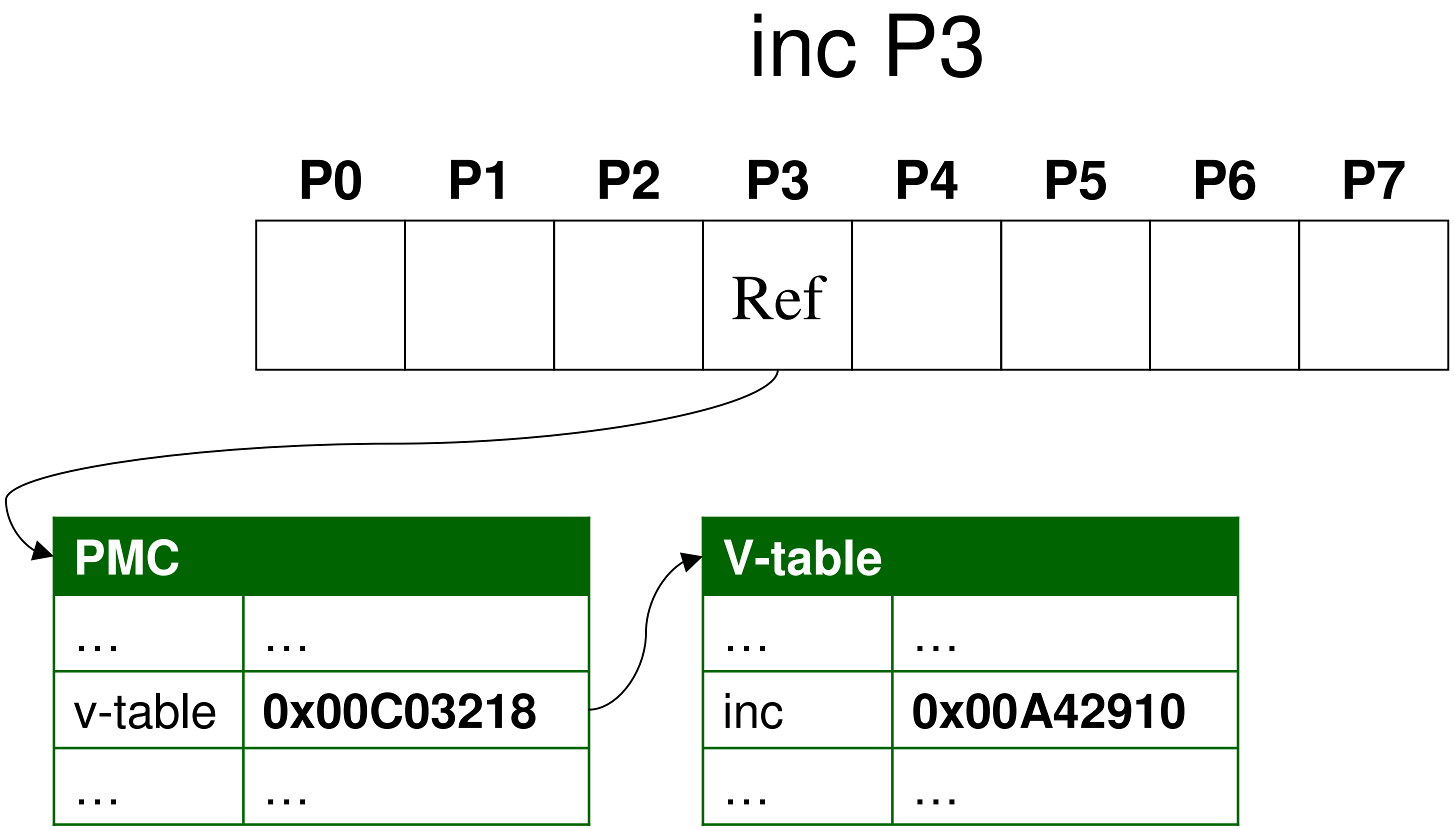

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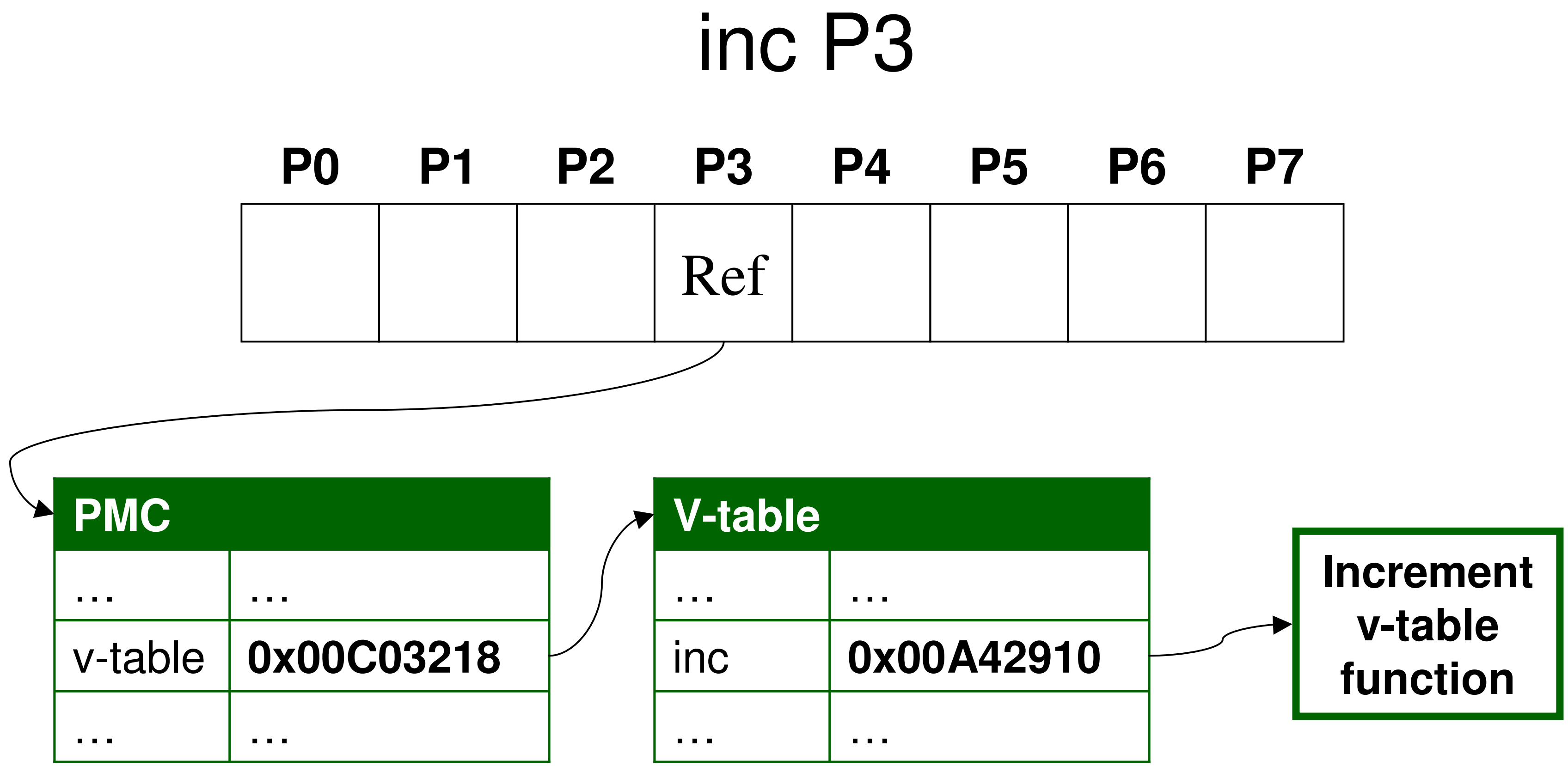

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PMCs allow language specific behaviour

- The same operation in two languages may produce very different behaviour.
- Consider the increment operator (++) performed on the string "ABC".
    - In Perl, the string becomes "ABD".
    - In Python, an exception is thrown.
- PerlString and PythonString PMCs can implement the "increment" method differently.

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PMCs support aggregate types

- PMCs have v-table methods for keyed get and set (where the key is an integer, string or PMC).
- These provide an interface for implementing arrays and dictionary data structures (such as hash tables).
- Storage mechanism left for the PMC to implement (e.g. a BitArray PMC could be implemented that uses 1 bit per element).

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PMCs enable language interoperability

- A Perl array may exhibit one set of behaviours (for example, automatically resizing) to a .NET one (which has a fixed size).
- As access to elements is through a common v-table interface, the internal representation and specific behaviours don't matter – Perl code can access elements from a .NET array and vice versa.

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And there's more…

- PMCs provide the basis for the Parrot class and object system, with v-table methods such as add_parent, add_method find_method, isa, can and more.
- Often used to provide an interface to Parrot internals and features; continuations and exceptions are represented as PMCs.
- PMCs simultaneously solve many problems through a single simple mechanism.

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Type extensibility

- As well as being built into the Parrot core, PMCs may be built into dynamically loaded libraries and loaded at runtime.
- Build tools make this no harder than writing PMCs for internal use.
- Currently, most of the Parrot internals are exposed – potential to crash the VM.
- Parrot needs a way to determine whether extensions being loaded are "trusted".

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Instruction extensibility

- Can also write extra VM instructions in a dynamically loaded library.
- Again, good build tools make this easy.
- Assembler needs to load the library, so it recognizes the mnemonics and can check the types.
- Can provide specialized, language-specific instructions without bloating the core VM.

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Instruction extensibility good?

- Dynamically loaded instructions can’t match the performance of core ones – for example, there is no way to JIT them.
- However, much cheaper dispatch overhead than calling a method on a PMC.
- They share the same trust issues that dynamically loaded PMCs do.
- I’m using them quite heavily with my .NET to Parrot bytecode translator.

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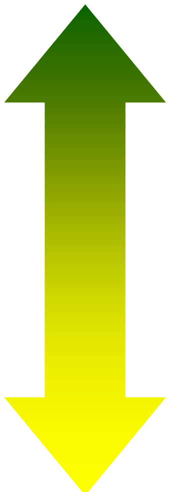
Parrot Programs

Parrot programs are mostly represented in one of three forms (an AST format exists, too).

Higher Level



Lower Level

PIR = Parrot Intermediate Representation

PASM = Parrot Assembly

PBC = Parrot Bytecode

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Parrot Intermediate Representation

```
.sub factorial
    .param int n
    .local int result

    if n > 1 goto recurse
    result = 1
    goto return

recurse:
    $I0 = n - 1
    result = factorial($I0)
    result *= n

return:
    .return (result)
.end
```

Simple sub declaration

Parameter access syntax

Named virtual registers

Register code looks like HLL

Virtual registers

Calling conventions hidden away

Return conventions hidden

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What does PASM look like?

Looks like assembly

Opcodes for returning

```
factorial:
    get_params "(0)", I1
    lt 1, I1, recurse
    set I0, 1
    branch return
recurse:
    sub I2, I1, 1
@pcc_sub_call_0:
    set_args “(0)”, I2
    set_p_pc P0, factorial
    get_results “(0)”, I1
    invokecc P0
    mul I0, I1
return:
@pcc_sub_ret_1:
    set_returns “(0)”, I0
    returncc
```

Opcode to get parameters

Calling conventions exposed

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What does PBC look like?

- A portable binary file format.
    - Written with the endianness and word size of the machine that generated it – good for performance.
    - If running on a different type of machine translation done “on the fly” – good for portability.
- Can be executed (almost) directly by the Parrot virtual machine.

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Why PIR, PASM and PBC?

- Need something that is efficient to load and directly execute – **PBC**
- Need something small to distribute – **PBC**
- Need something that is human readable and writable. – **PIR or PASM**
- Need a way to abstract away details (like calling conventions) from compilers – **PIR**
- Need low level assembly language – **PASM**

Looking at some HLL features

- Parrot provides support for a lot of HLL features to ensure interoperability.
- For example, it's nice if a Perl closure can be passed to some Common LISP code.
- If closures weren't implemented at a VM level, different compilers could do them differently.
- The final part of the talk looks at a few of the more interesting HLL features in Parrot.

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Lexical variables

- The needs of various languages with regards to lexical (statically scoped) variables differ somewhat.
- Many languages need to be able to look them up by name.
- Some but not all languages know what lexical variables they'll have at compile time.
- Then there's nesting and closures to think about...

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Lexical variables

- When lexicals are known at compile time, they can simply be stored in a register.
  - PIR syntax to associate name/register.

```
.lex "$x", P2
```

  - LexInfo PMC stores these mappings in a hash table.
  - Good performance – no need for "by name" lookup in common case and the mappings are frozen at compile time.

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Lexical variables

- Some languages don't know about lexicals until runtime (e.g. Tcl).
  - Can't associate a register with it; instead always lookup and store through ops.

```
store_lex "x", P0
...
P0 = find_lex "x"
```

  - LexPad PMC stores the lexical variables in a hash table, with their names being the keys.

Lexical variables - nesting

- Nesting is specified though a :outer(…) modifier on a sub.
- Take the following example Perl 6 program, which gives the result 42:

```
my $a = foo();
say $a();

sub foo() {
    my $x = 42;
    sub bar() { return $x; }
    return &bar; # Returns bar, doesn't call it
}
```

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Lexical variables - nesting

- Compiles to something like the following:

```
.sub foo
    .lex "$x", P0
    P0 = new Integer
    P0 = 42
    P1 = find_global "bar"
    .return(P1)
.end

.sub bar :outer(foo)
    P0 = find_lex "$x"
    .return(P0)
.end
```

```
.sub _main :main
    .lex "$a", P0
    P0 = foo()
    P1 = P0()
    print P1
    print "\n"
.end
```

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Lexical variables - closures

- A closure captures it's lexical environment.
  - This is formed by walking down the "outer chain" (not the call chain) and adding each lexical pad to it.
  - Optimization possible if we encounter an existing lexical environment.
- Nested subs are really creating a closure anyway – they're just closures that can take parameters.

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Namespaces

- Another places where different languages want different things, but we still want to have interoperability.
- Policy as well as technical issues.
    - Where does a language put its guts?
    - Are language's namespaces kept apart?
    - What about languages with sigils ($a, @b) sharing with those that don't (a, b)?

Namespaces - policy

- Top level namespaces will be:
  - HLL names, in lowercase, for user defined namespaces and data (perl6)
  - HLL names, in lowercase and prefixed with an underscore, for language internals (_perl6)
- This does mean that to use classes from another language, you'd need to know what language they were written in, unlike .NET.

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Namespaces - implementation

- Namespaces are hierarchical – that is, "Monkey::Abu" has the Abu namespace as a member of the Monkey namespace.
- A namespace itself is implemented as a PMC, and thus languages can provide their own specialised implementation.
- The (raw) interface is just a dictionary mapping names to PMCs (recall classes, subs, etc are PMCs).

Namespaces – implementation

- The raw interface is fine for use when the namespace "belongs" to the current HLL.
  - HLL code knows about name mangling and sigils.
- Additionally have a typed interface.
  - Hides away the quirks of a particular HLL's naming scheme.
  - Allows for HLL interoperability.

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Namespaces – typed interface

- The typed interface is provided as a number of methods on a namespace PMC.
  - Add, delete and find operations.
  - Differentiates between namespaces, subs and variables.
- Only about naming – no type checking.
- Doesn’t handle the scalar/array/hash sigil distinction, but can figure that out at runtime.

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Namespaces – export/import

- Exporter push rather than importer pull.
- "export_to" method on namespace PMC is provided with a list of symbols to export and the namespace to export them to.
  - Empty/null list => default exports
- Will usually use the typed interface on the destination namespace, but shortcuts and other evil are possible – just check the type of the namespace you're exporting to.

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Calling conventions

- Need a fairly rich calling convention to handle the needs of a wide variety of languages.
- This means Parrot needs to provide…
  - Both positional and named parameters
  - Optional parameters
  - “Slurpy” parameters
  - Multi-method dispatch

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Calling conventions – under the hood

- PIR syntax, as shown earlier, hides away the details.
- Actually have 4 instructions: set_args, get_params, set_returns and get_results.
- Take a signature PMC and a variable number of operands specifying the register number for each argument/return value.
- Register type comes from the signature.

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Calling conventions – performance

- In general, we can't perform as well as VMs such as .NET and the JVM, since the calling conventions are more complex.
- However, simple cases can be JITted.
- Furthermore, simple cases of tail calling can be optimized to iteration at JIT time.
- We can run the Languages Shootout Ackerman's function benchmark faster than optimized C (by GCC) on x86 and PPC!

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Future directions

- Parrot is still missing some Important Stuff.
  - Concurrency control – the plan is to implement STM, which will be needed to support Perl 6's more declarative style of concurrency (atomic and async blocks).
  - Completion of IO, AIO and events
  - Security subsystem (VMS inspired)
  - Parrot Grammar Engine for parsing

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Conclusions

- Parrot has some notable differences to the JVM and the .NET CLR.
- Trying to support many existing and quite different languages isn’t trivial.
- There’s much left to do, but also much already done – Parrot is running notable subsets of a range of languages.
- Any questions?