Domain specific languages: why? how? and where next?

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A question

What's this?

A question

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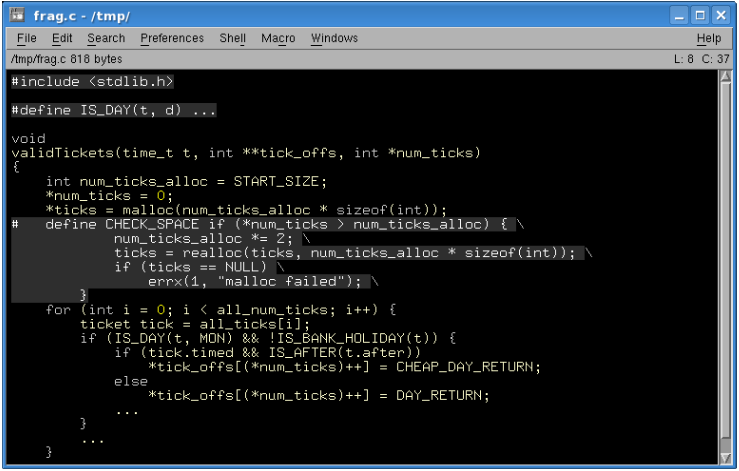
```
#include <stdlib.h>

#define IS_DAY(t, d) ...

void
validTickets(time_t t, int **tick_offs, int *num_ticks)
{
    int num_ticks_alloc = START_SIZE;
    *num_ticks = 0;
    *ticks = malloc(num_ticks_alloc * sizeof(int));
#   define CHECK_SPACE if (*num_ticks > num_ticks_alloc) { \
            num_ticks_alloc *= 2; \
            ticks = realloc(ticks, num_ticks_alloc * sizeof(int)); \
            if (ticks == NULL) \
                errx(1, "malloc failed"); \
        }
    for (int i = 0; i < all_num_ticks; i++) {
        ticket tick = all_ticks[i];
        if (IS_DAY(t, MON) && !IS_BANK_HOLIDAY(t)) {
            if (tick.timed && IS_AFTER(t.after))
                *tick_offs[(*num_ticks)++] = CHEAP_DAY_RETURN;
            else
                *tick_offs[(*num_ticks)++] = DAY_RETURN;
            ...
        }
        ...
    }
```

A question

What's this?



Is it a language for computers or a language for railway timetables?

The situation

- To express a solution we need a language.

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- To express a solution we need a language.
- On computers we turn to General Purpose Languages (GPLs)—e.g. Java, C#(), C++, Python, Ruby...
- For new or unusual problems, GPLs are nearly always great.
- But not always for repetitive tasks. Why?

Why do we have GPLs?

- Let's take Java.
- Main features: packages, classes, functions, static types, garbage collection, variables, `if`, `while`, `for`, and so on.

Why do we have GPLs?

- Let's take Java.
- Main features: packages, classes, functions, static types, garbage collection, variables, `if`, `while`, `for`, and so on.
- Really: building blocks.

Building blocks

- Virtually anything can be built with them...

Photo: David Iliff (licence)

Building blocks

- ...but it can be repetitive.

Photo: Mark Murphy (licence)

GPLs summary

- *Low level* building blocks.
- Virtually any task will need some (often all) of the building blocks.

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GPLs summary

- *Low level* building blocks.
- Virtually any task will need some (often all) of the building blocks.
- But few naturally map onto them.
- Very general; jacks of all trades, masters of none.
- The railway timetable uses only a tiny fraction of a GPLs power...

My GPL is better than yours

- But wait—my favourite language is better than Java!

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(l-r) Java, C++, Python, C#, Haskell

Source: Library & Archives Canada (licence)

My GPL is better than yours

- But wait—my favourite language is better than Java!
- GPLs are nearly all extremely similar.
- We magnify small differences for cultural reasons.
- They're all jack of all trades, master of none.

DSLs—the basic idea

- DSL: a small language targeted at a specific class of problems.
- Allows you to specify repetitive tasks with small amounts of variation.
- 'Do one thing and do it well.'

DSL examples

- SQL (databases)

Rev_Geo.py - /home/ltratt/work/elbatrop/src/locator/data/osm/

File Edit Search Preferences Shell Macro Windows Help

/home/ltratt/work/elbatrop/src/locator/data/osm/Rev_Geo.py 23949 bytes L: 436 C: 0

```
            if way1_id == highway_id and \
              dst1 + _DISTANCE_FROM_OTHER_HIGHWAY / Geo.metres_at_latitude(lat) < dst2:
                found = True

        if found:
            related.append(["W", way_id, dst])

    # Node case

    c.execute("""
      SELECT
        nodes.id, ST_Distance(ST_GeomFromEWKT(%(item_ll)s), nodes.geom) AS dst,
        ST_AsEWKT(nodes.geom)
      FROM nodes, node_tags AS nt1, node_tags AS nt2
      WHERE
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        AND nt1.node_id=nodes.id AND nt1.k='building'
        AND nt2.node_id=nodes.id AND (nt2.k='addr:housenumber' OR nt2.k='addr:housename')
      ORDER BY dst
      """, dict(highway_name=highway_name, item_ll=lls, \
      max_dst=_MAX_DISTANCE_OF_BUILDING / Geo.metres_at_latitude(lat)))
    c2 = db.cursor()
    for node_id, dst, node_geom in c.fetchall():
        c2.execute("""
          SELECT
            ways.id, ST_Distance(ST_GeomFromEWKT(%(node_geom)s), ways.linestring) AS dst
          FROM ways, way_tags
          WHERE
            ST_DWithin(ST_GeomFromEWKT(%(node_geom)s), ways.bbox, %(max_dst)s)
            AND way_tags.way_id=ways.id AND way_tags.k='highway'
          ORDER BY dst
          LIMIT 2
          """, dict(node_geom=node_geom, \
          max_dst=_MAX_DISTANCE_OF_BUILDING / Geo.metres_at_latitude(lat)))
        assert c2.rowcount > 0 and c2.rowcount <= 2
        found = False
        if c2.rowcount == 1:
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        else:
            way1_id, dst1 = c2.fetchone()
            way2_id, dst2 = c2.fetchone()
```
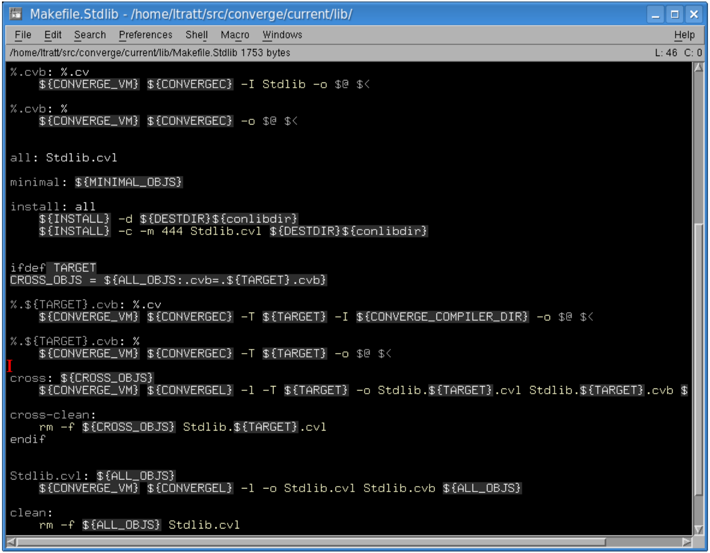

DSL examples

- make (software builds)




```
%.cvb: %.cv
	${CONVERGE_VM} ${CONVERGEC} -I Stdlib -o $@ $<

%.cvb: %
	${CONVERGE_VM} ${CONVERGEC} -o $@ $<


all: Stdlib.cvl

minimal: ${MINIMAL_OBJS}

install: all
	${INSTALL} -d ${DESTDIR}${conlibdir}
	${INSTALL} -c -m 444 Stdlib.cvl ${DESTDIR}${conlibdir}


ifdef TARGET
CROSS_OBJS = ${ALL_OBJS:.cvb=.${TARGET}.cvb}

%.${TARGET}.cvb: %.cv
	${CONVERGE_VM} ${CONVERGEC} -T ${TARGET} -I ${CONVERGE_COMPILER_DIR} -o $@ $<

%.${TARGET}.cvb: %
	${CONVERGE_VM} ${CONVERGEC} -T ${TARGET} -o $@ $<

cross: ${CROSS_OBJS}
	${CONVERGE_VM} ${CONVERGEL} -l -T ${TARGET} -o Stdlib.${TARGET}.cvl Stdlib.${TARGET}.cvb $

cross-clean:
	rm -f ${CROSS_OBJS} Stdlib.${TARGET}.cvl
endif


Stdlib.cvl: ${ALL_OBJS}
	${CONVERGE_VM} ${CONVERGEL} -l -o Stdlib.cvl Stdlib.cvb ${ALL_OBJS}

clean:
	rm -f ${ALL_OBJS} Stdlib.cvl
```

Hardware DSLs

- Question: are DSLs only for low-level software activities?

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- Verilog: hardware description language.

```
module counter (clk,rst,enable,count);
input clk, rst, enable;
output [3:0] count;
reg [3:0] count;

always @ (posedge clk or posedge rst)
if (rst) begin
  count <= 0;
end else begin : COUNT
  while (enable) begin
    count <= count + 1;
    disable COUNT;
  end
end

endmodule
```

Source: Deepak Kumar Tala

Why would we want DSLs?

- DSLs are good when we do the same type of task repeatedly.
- But is that it?

Consideration 1: accessibility

- Programming is how we tell computers what to do.

Consideration 1: accessibility

- Programming is how we tell computers what to do.
- Many (most?) people struggle with programming...

Consideration 1: accessibility

- DSLs can remove complex confusing features.

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- ```
  income tax {
    2010-2011 {
      allowance {
        age < 65: £6,475
        age >= 65 and age <= 74: £9,490
        age > 74: £9,640

        reduction: if income > £100,000 then
          max(0, allowance - ((income - £100,000) / 2))
      }
    }
  }
  ```

Tax rules source: HMRC
  ```

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- Sometimes complexity is fundamental.
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- Virtually all programming is done in imperative languages.
- Advantage: explicitness. Disadvantage: explicitness.
- DSLs are an abstraction over a domain.

Consideration 2: implementation flexibility

- SQL:

```
SELECT * FROM nodes WHERE node.parent=NULL;
```

- C:

```
table *nodes = get_table(db, "nodes");
cursor *c = mk_cursor(nodes);
row *r;
results res = mk_results();
while ((r = get_next(c)) != null) {
  if (get_column(r, "parent") == null)
    add_result(res, r);
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- How do you make parallelized versions of each?
- C: rewrite your program (pthreads etc.).
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Pros / cons:

+ Moves the burden from programmer to language implementer.
- Over-abstraction can preclude some reasonable programs.

Consideration 3: Economics

- The bottom line: does it save money?

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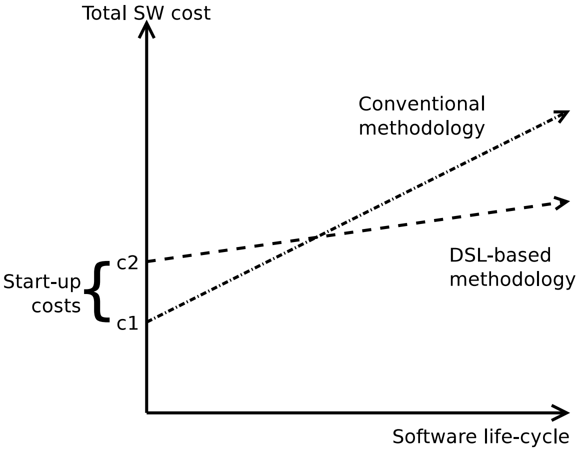
- The bottom line: does it save money?
- If you're using someone else's DSL: almost certainly yes.
- But if you need to build a DSL: it depends.

Consideration 3: Economics



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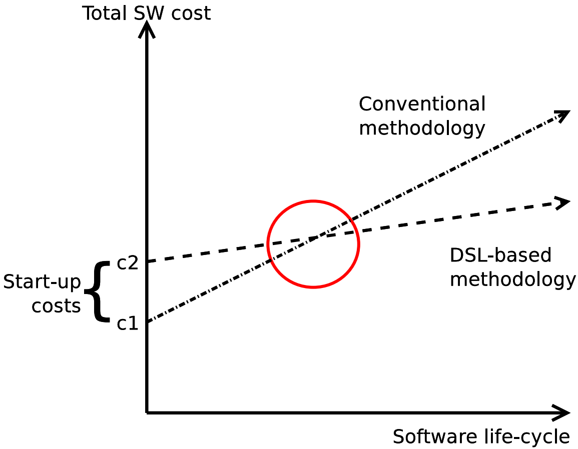
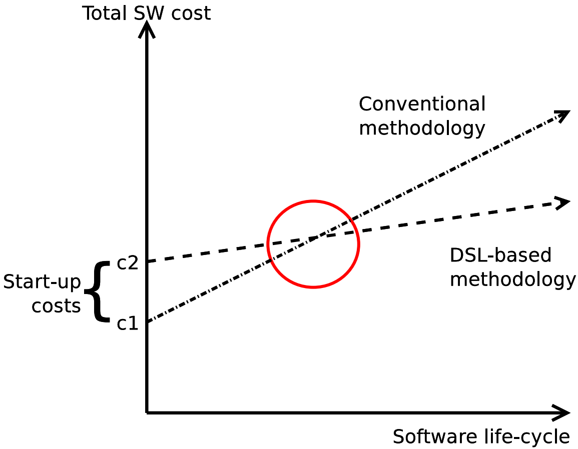


Source: P. Hudak 'Modular domain specific languages and tools'

Consideration 3: Economics



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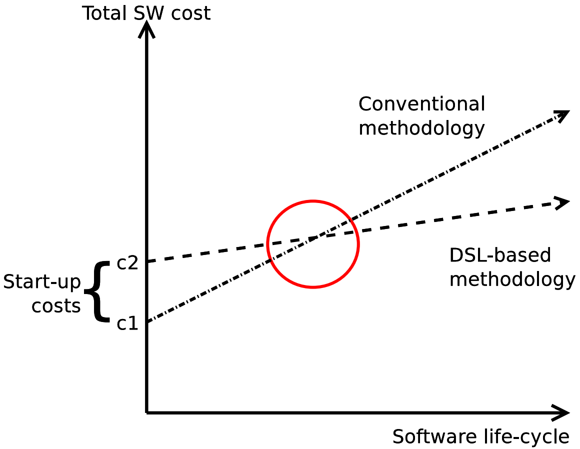
Consideration 3: Economics



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+ It can save *serious* amounts of money.
- Short-term hit for long-term gain.

What defines a DSL?

- [Inherently subjective and ill-defined. But...]

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What defines a DSL?

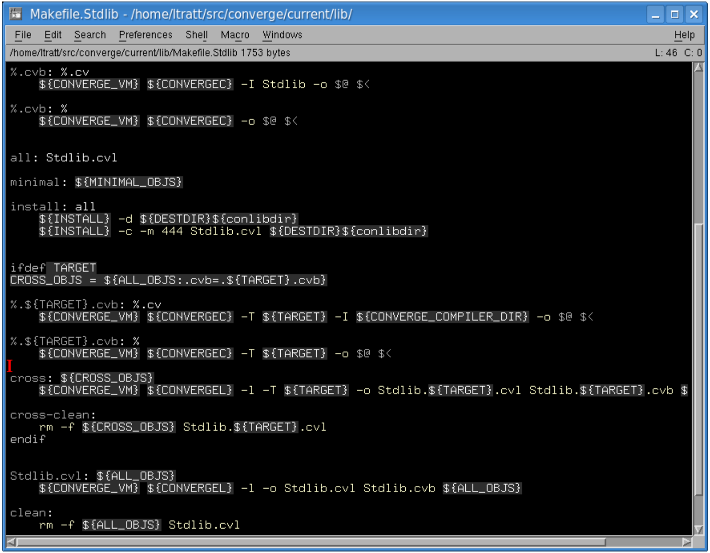
- [Inherently subjective and ill-defined. But...]
- Has a well-defined problem domain.
- Has its own syntax.
- [Practically speaking: its own implementation]

What DSLs aren't

- Haskell and Ruby people talk about 'internal DSLs'.
- Just a [clever?] way of using libraries.
- IMHO: not DSLs. Better called fluent interfaces.

DSL flavours

- `make`: standalone



DSL flavours

- SQL: embedded, syntactically distinct, run-time

Rev_Geo.py - /home/ltratt/work/elbatrop/src/locator/data/osm/

File Edit Search Preferences Shell Macro Windows Help

/home/ltratt/work/elbatrop/src/locator/data/osm/Rev_Geo.py 23949 bytes L: 436 C: 0

```
            if way1_id == highway_id and \
              dst1 + _DISTANCE_FROM_OTHER_HIGHWAY / Geo.metres_at_latitude(lat) < dst2:
                found = True

        if found:
            related.append(["W", way_id, dst])

    # Node case

    c.execute("""
      SELECT
        nodes.id, ST_Distance(ST_GeomFromEWKT(%(item_ll)s), nodes.geom) AS dst,
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      FROM nodes, node_tags AS nt1, node_tags AS nt2
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      ORDER BY dst
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      max_dst=_MAX_DISTANCE_OF_BUILDING / Geo.metres_at_latitude(lat)))
    c2 = db.cursor()
    for node_id, dst, node_geom in c.fetchall():
        c2.execute("""
          SELECT
            ways.id, ST_Distance(ST_GeomFromEWKT(%(node_geom)s), ways.linestring) AS dst
          FROM ways, way_tags
          WHERE
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            AND way_tags.way_id=ways.id AND way_tags.k='highway'
          ORDER BY dst
          LIMIT 2
          """, dict(node_geom=node_geom, \
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        assert c2.rowcount > 0 and c2.rowcount <= 2
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```

DSL flavours

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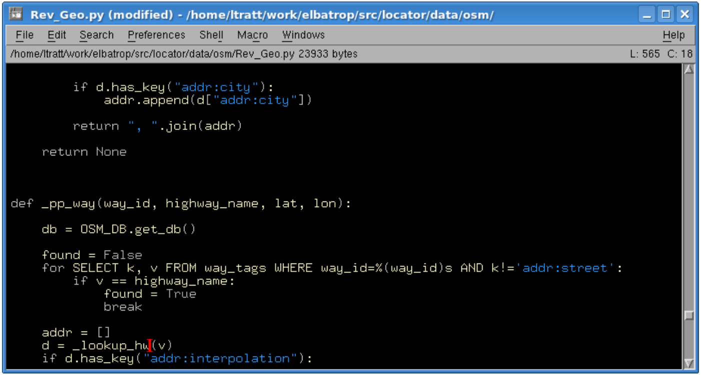
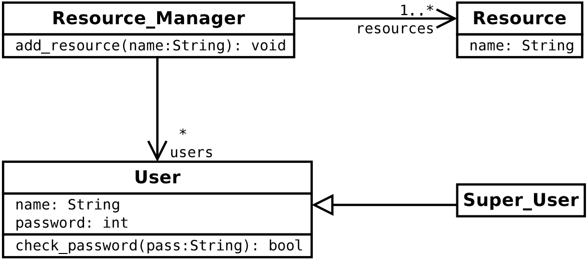



```
        if d.has_key("addr:city"):
            addr.append(d["addr:city"])

        return ", ".join(addr)

    return None


def _pp_way(way_id, highway_name, lat, lon):

    db = OSM_DB.get_db()

    found = False
    for SELECT k, v FROM way_tags WHERE way_id=%(way_id)s AND k!='addr:street':
        if v == highway_name:
            found = True
            break

    addr = []
    d = _lookup_hw(v)
    if d.has_key("addr:interpolation"):
```

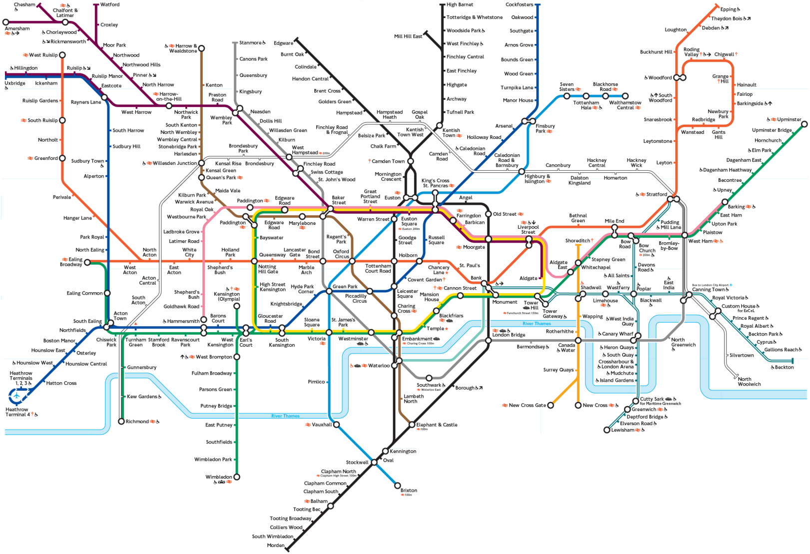
DSL flavours

- UML: diagrammatic



DSL flavours

- Metro systems: diagrammatic



DSL implementation techniques

A representative sample:

- Stand alone.
- Converge (embedded, homogeneous).
- Stratego (embedded / standalone, heterogeneous).
- Intentional (embedded, heterogeneous).
- MPS (embedded, homogeneous).
- Xtext (standalone, heterogeneous).

Part II: The Converge Language

What is Converge?

Converge has a number of influences. Relevant ones include:

- is dynamically, but strongly typed (think Python).
- is compiled to bytecode and run by a VM (think Java).
- can perform compile-time meta-programming (as Template Haskell, but probably easiest to think of macros in LISP/Scheme).
- can have its syntax extended (think MetaBorg).

Hello world

Compile-time meta-programming

This is the tricky, interesting bit. Code (as trees, not text) is programmatically generated.

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Expression	`2 + 3`	evaluates to `5` as one expects.
Splice	`$<x>`	evaluates `x` at compile-time; the AST returned overwrites the splice.
Quasi-quote	`[| 2 + 3 |]`	evaluates to a *hygienic* AST representing `2 + 3`.
Insertion	`[| 2 + ${x} |]`	'inserts' the AST `x` into the AST being created by the quasi-quotes.

An example

```
func expand_power(n, x):
  if n == 0:
    return [| 1 |]
  else:
    return [| $c{x} * $c{expand_power(n - 1, x)} |]

func mk_power(n):
  return [|
    func (x):
      return $c{expand_power(n, [| x |])}
  |]

power3 := $<mk_power(3)>
```

means that `power3` looks like:

```
power3 := func (x):
  return x * x * x * 1
```

by the time it is compiled to bytecode.

printf

What use is compile-time meta-programming?

- Now we have a modern programming language with macros...
- ...we can ‘compile’ arbitrary strings at compile time and...
- ...a DSL input is really just a string...

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- Now we have a modern programming language with macros...
- ...we can ‘compile’ arbitrary strings at compile time and...
- ...a DSL input is really just a string...
- But that is far as previous approaches have got...

Part III: DSLs in Converge

DSL creation in Converge

- DSLs use a simple layer on top of compile-time meta-programming.
- The sole language feature for DSLs is the *DSL block*.
- Allows embedding arbitrary strings using the indentation based syntax.

But first... parsing!

- Parsing is about finding the structure of text.
- Many ways to do this, but we'll look at one.
- Languages (natural or computer) have an underlying grammar.

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- Parsing is about finding the structure of text.
- Many ways to do this, but we'll look at one.
- Languages (natural or computer) have an underlying grammar.
- Simple English grammar:
  `sentence ::= subject verb object`
- e.g. `Bill hits Ben`

Parsing phases

- Simplest way: tokenize then parse.
- Tokenize: split input up into individual tokens. [e.g. in English split words by the presence of spaces or punctuation]. Creates list of tokens.
- Parse: work out the sturcture of the tokens relative to the grammar. Creates a parse tree.

Parsing phases

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- Tokenize: split input up into individual tokens. [e.g. in English split words by the presence of spaces or punctuation]. Creates list of tokens.
- Parse: work out the sturcture of the tokens relative to the grammar. Creates a parse tree.
- Tokenization is generally easy.
- Parsing isn't: use a grammar formalism to help.

BNF

- Context Free Grammars (CFGs) can express most programming languages.
- Earley parsing can parse any CFG, so use that.
- Backus-Naur Form (BNF): the standard(ish) way of specifying CFGs.
- A very simple calculator grammar:

```
E ::= INT "+" INT
    | INT "*" INT
```

- Now we can do a 'yes/no' parse of `2 + 3` and `6 * 2`.

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- Now we can do a 'yes/no' parse of `2 + 3` and `6 * 2`.
- But 'yes/no' isn't very useful: build parse trees.

Self-referencing rules

- A better calculator:

```
E ::= E "+" E
    | E "*" E
    | INT
```

- What parse tree will we get for `2 + 3 * 4`?

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E ::= E "+" E %precedence 0
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Higher precedences are preferred.

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  Higher precedences are preferred.
- An aside: in general, it's not known how to statically detect ambiguities in arbitrary CFGs. Ambiguities are sort-of run-time errors.

EBNF

- A simplified EBNF grammar... for EBNF!

```
Grammar ::= Rule*

Rule    ::= ID "::=" Prod ( "|" Prod )*

Prod    ::= Expr*

Expr    ::= ID
          | STRING
          | "(" Expr* ")"
          | Expr "*"
```

[Don't worry if this makes your head hurt for the moment.]

Simplifying parsing

- Hudak: syntax extension is bad. (Because parsing is horrid).
- Converge aims to make parsing easy.
- Converge's tokenizer (a.k.a. lexer) is designed for use by non-Converge languages.
- It can be told to parse new keywords and 'unknown' symbols.
- Converge has a built in Earley parser; can parse *any* CFG.
- Writing a grammar for an Earley parser is easy.

Example

Error reporting (1)

- Another problem with new syntax: error reporting goes out of the window.
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- Another problem with new syntax: error reporting goes out of the window.
- Languages with macro systems provide little or no error reporting.
- DSL development is intolerable without accurate error reporting.
- Converge has evolved a unique approach to error reporting.
- Errors identify file name, line number, and column numbers.

Error reporting (2)

- ‘Src info’ a (src path, src offset, src len) triple.
- ‘Src info’ concept pervasive: tokenizer, parser, ASTs, bytecode generator, and VM.
- Every token, AST element, and bytecode instruction associated with one *or more* src infos. Trivial to pinpoint errors as having occurred *within* a DSL block.
- Users can add extra src info to AST elements in various ways.
- e.g. To associate the AST built by a quasi-quote with both the quasi-quote and a position in a DSL, use this syntax:

```
[<node[1].src_infos>| ${foo}[0] |]
```

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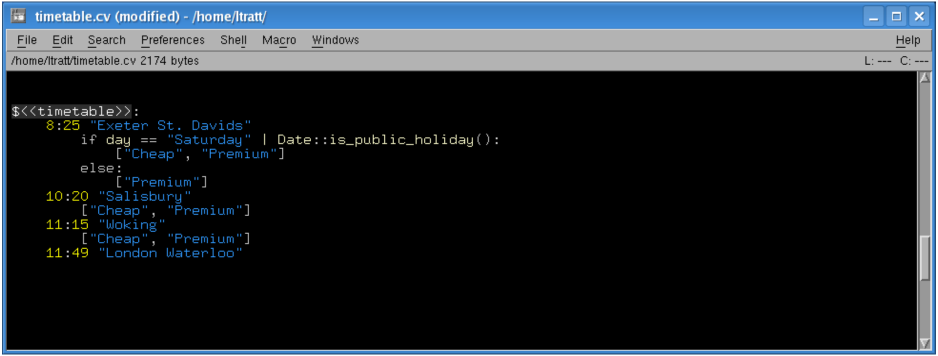
- Many stand alone DSLs have hackish, buggy, expression languages.
- If the standard Converge tokenizer is used for a DSL, Converge's expression language can be embedded within the DSL.
- Code reuse at its best!



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Converge gives you huge assistance for everything but step 5!

Current state of affairs

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- Pre-built binaries for Linux / OpenBSD / OS X / Windows.
- More at http://convergepl.org/.
- Currently working on a new RPython-based VM: about 2/3 complete and about 4x faster than the old VM (aiming to get $\tilde{6}$-8x faster). https://github.com/ltratt/converge/tree/pypyvm/pypyvm.

Part IV: The future

Parsing

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- As far as I can tell, no good solution known.

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- Syntax directed editing has no composition problems...
- ...but tried and rejected in the 80s.
- MPS shows it can be (at least) semi-palatable.
- [Maybe the Intentional tool, if we ever get to play with it.]

Composition

- Next major challenge: composing language implementations.
- Not Java $+$ C++ (yet).
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Further reading

- Fowler: Language workbenches
- Stahl, Völter: Model-Driven Software Development
- Vasudevan, Tratt: Comparative study of DSL tools

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Thanks for listening