Relations FIRST and FOLLOW for Parsing Expression Grammar

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What is Parsing Expression Grammar?

The last fad in top-down parsing with limited backtracking.

- 1961 Brooker & Morris - Altas Compiler Compiler
- 1965 McClure - TransMoGrifier (TMG)
- 1972 Aho & Ullman - Top-Down Parsing Language (TDPL)
- ...
- 2004 Ford - Parsing Expression Grammar (PEG)

Parsing Expression Grammar (PEG)

```
number  = real / integer
real    = digits? "." digits
integer = digits
digits  = [0-9][0-9]*
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Note: not LL(1).

PEG in action

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number  = real / integer
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digits  = [0-9][0-9]*
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PEG in action

```
number  = real / integer
real    = digits? "." digits
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          29.165
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number  = real / integer
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number
```

PEG in action

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number  = real / integer
real    = digits? "." digits
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number->real
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number  = real / integer
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number->real->digits
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PEG in action

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number->real->digits->[0-9][0-9]*
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number->real->digits->[0-9][0-9]*: consume "29"
```

PEG in action

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           29.165
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number->real->"."
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number->real->".": consumes "."
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number->real->digits: consume "165"
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```
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           ^
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PEG in action: backtracking

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number->real->digits: consume "4711"
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number->real: backtracks
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number->integer->digits: consume "4711"
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Once `number` succeeded, nothing can force it to try `real`.

`integer` hides part of the language of `real`.

PEG is not EBNF

All of these fail on input `aab`:

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("a"/"aa")"b"    – "a" consumes a, "b" fails on ab

("aa"/"a")"ab"

("a"/"c"?)"aab"
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```

Not easy to see what happens in a complex grammar.

Some fun

Guess what this is doing:

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A = "a"A"a" / "aa"
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Result depends on input far ahead.

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Programmer's paradise: write, try, debug, show your skill.

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  understand what this damned thing is doing.

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- How about just some hints where to look?
- Observation: problems are associated
  with LL(1) violations.
- Suggestion: detect LL(1) violations.
- How: adapt known techniques to PEG.

Classical FIRST and FOLLOW

A known technique to check for LL(1) uses these relations:

- FIRST(s) - set of possible first letters in a string derived from grammar symbol s.
- FOLLOW(s) - set of possible letters that can follow a string derived from grammar symbol s.

Adapted to PEG:

- FIRST(e) - set of terminals that may be invoked by expression e on the start of input.
- $\text{FOLLOW}_s(e)$ - set of expressions that may be invoked after success of e.
- $\text{FOLLOW}_f(e)$ - set of expressions that may be invoked after failure of e.

Disjoint expressions

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Example:

$$e_1 = \texttt{"abc"[a-z]}^* \qquad \text{FIRST}(e_1) = \{\texttt{"abc"}\},$$
$$e_2 = \texttt{"abd"[a-z]}^* \qquad \text{FIRST}(e_2) = \{\texttt{"abd"}\},$$
$$e_3 = \texttt{[a-z][a-z]}^* \qquad \text{FIRST}(e_3) = \{\texttt{[a-z]}\}$$

e_1 and e_2 are disjoint.
e_2 and e_3 are not.

Main result

Disjoint choice $e_1 / \ldots / e_n$: all $e_1, \ldots, e_n$ are pairwise disjoint.

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2. If any of $e_1, \ldots, e_n$ in a disjoint choice fails after succeeding with at least one terminal, no terminal will succeed on that input. (Until the parser backtracks and takes another try.)

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   - We can flag non-disjoint choices for examination.

2. If any of $e_1, \dots, e_n$ in a disjoint choice fails after succeeding with at least one terminal, no terminal will succeed on that input. (Until the parser backtracks and takes another try.)

   - We can stop trying other alternatives.
   This a PEG version of predictive parsing.
   (Mizushima, Meada & Yamaguchi)

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There is a similar theory for star expressions that uses FOLLOW_s.

But this is a long story...
See CS&P 2008, Fundamenta Inf. 93.

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Let us see why.

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Lookahead expression: $!e$ where e is any expression.

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- Make sure the input does not start with `abc`.
- But do not consume anything.

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- Make sure the input does not start with `abc`.
- But do not consume anything.
- `"abc"` is included in FIRST.

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e_1 = `(!"abc")[a-z]*`,
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They never succeed on the same input.

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FIRST(e_1) = {"abc", [a-z]} (yes, e_1 tries both),
FIRST(e_2) = {"abc"}.

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FIRST(e_1) = {`"abc"`, `[a-z]`} (yes, e_1 tries both),
FIRST(e_2) = {`"abc"`}.

They are flagged as non-disjoint.

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$\text{FIRST}(e_1) = \{$`"abc"`, `[a-z]`$\}$ is clearly too big.

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are still not disjoint.

We need something like FIRST(e_1) $=$ {`[a-z]` but not `"abc"`}.

Unfortunately, this does not work in general.
We need something new.

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Define "*e* bites *s*" to mean "a terminal called by *e*, otherwise than via a lookahead, consumes a prefix of *s*".

(In other words, *e* takes the first real step to consume *s*.)

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`(!"abc")[a-z]`* bites any string in $\overline{\texttt{"abc"}\Sigma^*} \cap \texttt{[a-z]}\Sigma^*$.

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$\text{BITES}(\texttt{[a-z]}^*) = \texttt{[a-z]}\Sigma^*$.

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Examples:

BITES(`[a-z]*`) $=$ `[a-z]`Σ^*.

BITES(`"abc"[a-z]*`) $=$ `"abc"`Σ^*.

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e bites s $\Rightarrow$ $s \in$ BITES(e).

Examples:

BITES(`[a-z]*`) $=$ `[a-z]`Σ^*.

BITES(`"abc"[a-z]*`) $=$ `"abc"`Σ^*.

BITES(`(!"abc")[a-z]*`) $= \overline{\texttt{"abc"}\Sigma^*} \cap$ `[a-z]`Σ^*.

New disjointness

$\text{BITES}(e_1) \cap \text{BITES}(e_2) = \varnothing$ means:

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`"abc"[a-z]*` and `(!"abc")[a-z]*` are now disjoint!

Updated main results

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1. Language hiding does not occur in a disjoint choice.
2. If any of $e_1, \ldots, e_n$ in a disjoint choice fails after biting the input, nothing will bite that input. (Until the parser backtracks and takes another try.)

Everything fine? Not really...

The lookahead is still a problem.

$$\text{BITES}((!e_1)e_2) = \overline{\text{SUCC}(e_1)} \cap \text{BITES}(e_2)$$

where $\text{SUCC}(e_1)$ should be the set of strings on which e_1 succeeds.

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Finding $\text{SUCC}(e)$ for arbitrary e is difficult.

It is about e succeeding on s, not just biting it.
And remember, it may depend on input far ahead.
(Back to square one?)

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(We have to preserve "e bites $s \Rightarrow s \in \text{BITES}(s)$".)

One such approximation is $\widetilde{\text{SUCC}}(e) = \varnothing$

which gives $\text{BITES}((!e_1)e_2) = \text{BITES}(e_2)$, loosing all info on e_1.

Not good, but I do not see any better yet.

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with Boolean operations.

Of course, the emptiness problem for such expressions
is decidable, but standard procedures are cumbersome
with a large alphabet.

Conclusions

1. BITES is better than FIRST, but still not perfect.
2. BITES is more difficult to implement,
   but this is one-off, not run-time, analysis.
3. There is still much left to be detected.

What next

1. Implement and see how it works?
2. Forget it?
3. More research? (Need something for CSP 2011...)

That's all folks ...

Thanks for your attention!