Universiteit Utrecht

[Faculty of **Science**
Information and Computing Sciences]

Lectures C: Parser Combinators - Introduction

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1. Elementary Parser Combinators

1.1 What are parser combinators

What are parser combinators

§1.1

- a collection basic parsing functions that recognise a piece of input
- a collection of combinators that build new parsers out of existing ones

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- a collection basic parsing functions that recognise a piece of input
- a collection of combinators that build new parsers out of existing ones

For the time being parsers are just Haskell functions, but we will extend on that later.

1.2 Elementary Combinators

Elementary Parsers

§1.2

All libraries are based on at least the following four basic combinators:

Elementary Parsers

All libraries are based on at least the following four basic combinators:

	Haskell
alternative	p <|> p
composition	p <*> q
terminals	*pSym* `'s'`
empty string	*pSucceed*

Building Parsers out of Parsers

§1.2

Other operators:

Building Parsers out of Parsers

Other operators:

		Haskell
repetition	$a*$	*pMany a*
option	$a?$	‘*opt*‘ *a*
grouping	$(\ldots)$	$(\ldots)$

The Type of a Parser

A parser takes a string and returns result of type a

$$String \rightarrow a$$

The Type of a Parser

A parser may be ambiguous, and there may be many possible ways of recognizing a value of type a:

> $String \rightarrow [a]$

The Type of a Parser

§1.2

A parser may not consume the whole input, and now also returns the unused part of the input:

$$String \rightarrow [(a, String)]$$

The Type of a Parser

§1.2

Why should we only accept character strings? Everything goes, as long as we have equality defined for the tokens:

$$Eq\ s \Rightarrow [s] \rightarrow [(a, [s])]$$

The Type of a Parser

Why should we only accept character strings? Everything goes, as long as we have equality defined for the tokens:

$$Eq\ s \Rightarrow [s] \rightarrow [(a, [s])]$$

Which we give a name:

$$\textbf{type}\ Parser\ s\ a = Eq\ s \Rightarrow [a] \rightarrow [(a, [s])]$$

Types of the Elementary Combinators

Types

$$<|> \quad :: \mathit{Parser}\ s\ a \quad \rightarrow \mathit{Parser}\ s\ a \rightarrow \mathit{Parser}\ s\ a$$

Try to remember these types. Knowing the types is half the work when programming in Haskell.

Types of the Elementary Combinators

Types

$$
\begin{array}{lll}
<|> & :: Parser\ s\ a & \rightarrow Parser\ s\ a \rightarrow Parser\ s\ a \\
<*> & :: Parser\ s\ a & \rightarrow Parser\ s\ b \rightarrow Parser\ s\ (a, b)
\end{array}
$$

Try to remember these types. Knowing the types is half the work when programming in Haskell.

Types of the Elementary Combinators

Types

$$
\begin{aligned}
<|> &:: \mathit{Parser}\ s\ a \rightarrow \mathit{Parser}\ s\ a \rightarrow \mathit{Parser}\ s\ a \\
<*> &:: \mathit{Parser}\ s\ (b \rightarrow a) \rightarrow \mathit{Parser}\ s\ b \rightarrow \mathit{Parser}\ s\ a
\end{aligned}
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<|> & :: Parser\ s\ a & \rightarrow Parser\ s\ a \rightarrow Parser\ s\ a \\
<*> & :: Parser\ s\ (b \rightarrow a) & \rightarrow Parser\ s\ b \rightarrow Parser\ s\ a \\
pSym & :: s & \rightarrow Parser\ s\ s
\end{array}
$$

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Types

$$
\begin{array}{lll}
<|> & :: Parser\ s\ a & \rightarrow Parser\ s\ a \rightarrow Parser\ s\ a \\
<*> & :: Parser\ s\ (b \rightarrow a) & \rightarrow Parser\ s\ b \rightarrow Parser\ s\ a \\
pSym & :: s & \rightarrow Parser\ s\ s \\
pSucceed & :: \quad a & \rightarrow Parser\ s\ a
\end{array}
$$

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<*> & :: & Parser\ s\ (b \rightarrow a) \rightarrow Parser\ s\ b \rightarrow Parser\ s\ a \\
pSym & :: & s \rightarrow Parser\ s\ s \\
pSucceed & :: & a \rightarrow Parser\ s\ a \\
pFail & :: & Parser\ s\ a
\end{array}
$$

Try to remember these types. Knowing the types is half the work when programming in Haskell.

1.3 The “List of Successes” Implementation

The "List of Successes" Implementation §1.3

$$pFail \qquad inp = [\,]$$

The "List of Successes" Implementation §1.3

$$
\begin{aligned}
&\mathit{pFail} && \mathit{inp} = [\,] \\
&\mathit{pSucceed}\ v && \mathit{inp} = [\,(v, \mathit{inp})\,]
\end{aligned}
$$

The "List of Successes" Implementation §1.3

$$
\begin{aligned}
&\mathit{pFail} && \mathit{inp} = [\,] \\
&\mathit{pSucceed}\ v && \mathit{inp} = [\,(v, \mathit{inp})\,] \\
&(p \mathbin{<|>} q) && \mathit{inp} = p\ \mathit{inp} \mathbin{+\!\!+} q\ \mathit{inp}
\end{aligned}
$$

The "List of Successes" Implementation §1.3

$$
\begin{array}{lll}
\mathit{pFail} & \mathit{inp} = [\,] & \\
\mathit{pSucceed}\ v & \mathit{inp} = [(v, \mathit{inp})] & \\
(p <|> q) & \mathit{inp} = p\ \mathit{inp} +\!\!+ q\ \mathit{inp} & \\
\mathit{pSym}\ a & \mathit{inp} = \textbf{case}\ \mathit{inp}\ \textbf{of} & \\
 & \quad (s : ss) \rightarrow \textbf{if} \quad a \equiv s & \\
 & \qquad\qquad\quad \textbf{then}\ [(s, ss)] & \\
 & \qquad\qquad\quad \textbf{else}\ [\,] & \\
 & \quad [\,] \qquad \rightarrow [\,] &
\end{array}
$$

The "List of Successes" Implementation §1.3

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\mathit{pFail} & \mathit{inp} = [\,] & \\
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\mathit{pSym}\ a & \mathit{inp} = \textbf{case}\ \mathit{inp}\ \textbf{of} & \\
 & \quad (s : ss) \rightarrow \textbf{if} & a \equiv s \\
 & \qquad\qquad\quad \textbf{then} & [\,(s, ss)\,] \\
 & \qquad\qquad\quad \textbf{else} & [\,] \\
 & \quad [\,] \rightarrow [\,] & \\
(p \mathbin{<*>} q) & \mathit{inp} = [\ (a2b\ a,\ rr) & \\
 & \quad \mid (a2b\ \ ,\ r) & \leftarrow p\ \mathit{inp} \\
 & \quad ,\ (a\ \ ,\ rr) & \leftarrow q\ r \\
 & \quad] &
\end{array}
$$

Computing a Result

§1.3

The question which arises now is how do we get something useful out of such parsers?

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We recognize a character `'B'`:

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Preceded by the recognition of a character `'A'`

$$pSym\ \texttt{'A'} \qquad pSym\ \texttt{'B'}$$

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The question which arises now is how do we get something useful out of such parsers?

We recognize a character `'B'`:

$$pSym\ \texttt{'B'}$$

Preceded by the recognition of a character `'A'`

$$pSym\ \texttt{'A'} \qquad pSym\ \texttt{'B'}$$

We now insert a dummy parser that returns the function $(,)$:

$$pSucceed\ (,) \qquad pSym\ \texttt{'A'} \qquad pSym\ \texttt{'B'}$$

Computing a Result

The question which arises now is how do we get something useful out of such parsers?

We recognize a character `'B'`:

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Preceded by the recognition of a character `'A'`

$$pSym\ \texttt{'A'} \qquad pSym\ \texttt{'B'}$$

We now insert a dummy parser that returns the function $(,)$:

$$pSucceed\ (,) \qquad pSym\ \texttt{'A'} \qquad pSym\ \texttt{'B'}$$

Combine the result using sequential composition of parsers:

$$pAB = \quad pSucceed\ (,) \mathbin{<\!*\!>} pSym\ \texttt{'A'} \mathbin{<\!*\!>} pSym\ \texttt{'B'}$$

1.4 Extensions

Useful functions I

§1.4

Because the pattern:

$$pSucceed\ f\ <\!*\!>\ p$$

occurs so often

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$$pSucceed\ f\ <*>\ p$$

occurs so often we define

<$>

$$f\ <\$>\ p = pSucceed\ f\ <*>\ p$$

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Because the pattern:

$$pSucceed\ f\ <\!*\!>\ p$$

occurs so often we define

<$>

$$f\ <\$>\ p = pSucceed\ f\ <\!*\!>\ p$$

so we can write the previous function as:

$$pAB = (,)\ <\$>\ pSym\ \texttt{'A'}\ <\!*\!>\ pSym\ \texttt{'B'}$$

Useful functions II

Often we are not interested in parts of what we have recognized:

$$
\begin{aligned}
&\mathit{semIfStat}\ \mathit{cond}\ \mathit{ifpart}\ \mathit{thenpart} = \ldots \\
&\mathit{pIfStat} = (\lambda\_\ c\ \_\ t\ \_\ e\ \_ \quad \rightarrow \mathit{semIfStat}\ c\ t\ e) \\
&\qquad \langle\$\rangle\ \mathit{pIfToken} \quad \langle*\rangle\ \mathit{pExpr} \\
&\qquad \langle*\rangle\ \mathit{pThenToken}\ \langle*\rangle\ \mathit{pExpr} \\
&\qquad \langle*\rangle\ \mathit{pElseToken}\ \langle*\rangle\ \mathit{pExpr} \\
&\qquad \langle*\rangle\ \mathit{pFiToken}
\end{aligned}
$$

Useful functions II

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\begin{aligned}
&\mathit{semIfStat}\ \mathit{cond}\ \mathit{ifpart}\ \mathit{thenpart} = \ldots \\
&\mathit{pIfStat} = (\lambda\_\ c\ \_\ t\ \_\ e\ \_ \quad \rightarrow \mathit{semIfStat}\ c\ t\ e) \\
&\qquad\qquad <\$> \mathit{pIfToken} \quad <*> \mathit{pExpr} \\
&\qquad\qquad <*> \mathit{pThenToken} <*> \mathit{pExpr} \\
&\qquad\qquad <*> \mathit{pElseToken} <*> \mathit{pExpr} \\
&\qquad\qquad <*> \mathit{pFiToken}
\end{aligned}
$$

We define

$$
\begin{aligned}
p <*\ \ q &= (\lambda x\ \_ \rightarrow x) <\$> p <*> q \\
p\ \ *> q &= (\lambda\_\ y \rightarrow y) <\$> p <*> q \\
f <\$\ \ q &= \mathit{pSucceed}\ f <*\ \ q
\end{aligned}
$$

Useful functions II

We define

$$
\begin{aligned}
p \mathbin{<\!*} q &= (\lambda x \_ \to x) \mathbin{<\$>} p \mathbin{<\!*\!>} q \\
p \mathbin{*\!>} q &= (\lambda \_\, y \to y) \mathbin{<\$>} p \mathbin{<\!*\!>} q \\
f \mathbin{<\$} q &= \mathit{pSucceed}\, f \mathbin{<\!*} q
\end{aligned}
$$

So we can now write:

$$
\begin{aligned}
\mathit{pIfStat} = \mathit{semIfStat} \mathbin{<\$} \; & \mathit{pIfToken} \mathbin{<\!*\!>} \mathit{pExpr} \\
\mathbin{<\!*} \; & \mathit{pThenToken} \mathbin{<\!*\!>} \mathit{pExpr} \\
\mathbin{<\!*} \; & \mathit{pElseToken} \mathbin{<\!*\!>} \mathit{pExpr} \\
\mathbin{<\!*} \; & \mathit{pFiToken}
\end{aligned}
$$

Useful functions II

We define

$$
\begin{aligned}
p \mathbin{<\!*} q &= (\lambda x \_ \to x) \mathbin{<\$>} p \mathbin{<\!*\!>} q \\
p \mathbin{*\!>} q &= (\lambda \_\, y \to y) \mathbin{<\$>} p \mathbin{<\!*\!>} q \\
f \mathbin{<\$} q &= \mathit{pSucceed}\, f \mathbin{<\!*} q
\end{aligned}
$$

So we can now write:

$$
\begin{aligned}
\mathit{pIfStat} = \mathit{semIfStat} \mathbin{<\$} \; & \mathit{pIfToken} \mathbin{<\!*\!>} \mathit{pExpr} \\
\mathbin{<\!*} \; & \mathit{pThenToken} \mathbin{<\!*\!>} \mathit{pExpr} \\
\mathbin{<\!*} \; & \mathit{pElseToken} \mathbin{<\!*\!>} \mathit{pExpr} \\
\mathbin{<\!*} \; & \mathit{pFiToken}
\end{aligned}
$$

Functions like *semIfStat* are generated by the *uuagc* compiler.

EBNF extensions


```
infixl 2 opt
opt          :: Parser s a→a→Parser s a
p `opt` v = p <|> pSucceed v
```

In the library we have special greedy versions which choose the longest alternative.

EBNF extensions


```
infixl 2 opt
opt          :: Parser s a→a→Parser s a
p `opt` v = p <|> pSucceed v
```

```
pList   :: Parser s a→Parser s [a]
pList p = (:) <$> p <*> pList p `opt` []
```

In the library we have special greedy versions which choose the longest alternative.

Exercise

Write a function that recognises a sequence of balanced parentheses, (i.e. $(), (()), (() \ ()) \ (), \ldots$, and computes the maximal nesting depth (here $1, 2, 2, \ldots$.

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$$
\begin{aligned}
pP &= (max \cdot (+1)) \mathbin{<\$>} pPack\ pP \mathbin{<*>} pP \\
&\quad \text{`}opt\text{`}\ 0 \\
pPack\ p &= pSym\ \text{'('} \mathbin{*>} p \mathbin{<*} pSym\ \text{')'}
\end{aligned}
$$

Chaining

$$
\begin{aligned}
&\mathit{pChainr} :: \mathit{Parser}\ s\ (c \to c \to c) \to \mathit{Parser}\ s\ c \to \mathit{Parser}\ s\ c \\
&\mathit{pChainr}\ \mathit{sep}\ p = p \\
&\qquad\qquad <|> (\lambda \mathit{pres}\ \mathit{op}\ \mathit{chres} \to \mathit{pres}\ \text{`}\mathit{op}\text{`}\ \mathit{chres}) \\
&\qquad\qquad\qquad <\$> p <*> \mathit{sep} <*> \mathit{pChainr}\ \mathit{sep}\ p
\end{aligned}
$$

Chaining


```
pChainr :: Parser s (c→c→c)→Parser s c→Parser s c
pChainr sep p = p
                <|> (λpres op chres→pres `op` chres)
                    <$> p <*> sep <*> pChainr sep p
```

```
pChainl :: Parser s (c→c→c)→Parser s c→Parser s c
pChainl op x = (f <$> x <*> pList (flip <$> op <*> x))
               where
               f x [] = x
               f x (func : rest) = f (func x) rest
```

Left Factorisation

It is not a good idea to have parsers that have alternatives starting with the same element:

$$
\begin{aligned}
p = \quad & f \mathbin{<\$>} q \mathbin{<*>} r1 \\
\mathbin{<|>}\ & g \mathbin{<\$>} q \mathbin{<*>} r2
\end{aligned}
$$

Left Factorisation

It is not a good idea to have parsers that have alternatives starting with the same element:

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\end{aligned}
$$

So we define:

$$
\begin{aligned}
& p \mathbin{<**>} q :: \mathit{Parser}\ s\ b \rightarrow \mathit{Parser}\ s\ (b \rightarrow a) \rightarrow \mathit{Parser}\ s\ a \\
& p \mathbin{<**>} q = (\lambda pv\ qv \rightarrow qv\ pv) \mathbin{<\$>} p \mathbin{<*>} q
\end{aligned}
$$

Left Factorisation

It is not a good idea to have parsers that have alternatives starting with the same element:

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p = \quad & f \mathbin{<\$>} q \mathbin{<*>} r1 \\
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So we define:

$$
\begin{aligned}
& p \mathbin{<**>} q :: \mathit{Parser}\ s\ b \to \mathit{Parser}\ s\ (b \to a) \to \mathit{Parser}\ s\ a \\
& p \mathbin{<**>} q = (\lambda pv\ qv \to qv\ pv) \mathbin{<\$>} p \mathbin{<*>} q
\end{aligned}
$$

So we can replace the above code by:

$$
\begin{aligned}
& p = q \mathbin{<**>} (\mathit{flip}\ f \mathbin{<\$>} r1 \mathbin{<|>} \mathit{flip}\ g \mathbin{<\$>} r2) \\
& \mathit{flip}\ f\ x\ y = f\ y\ x
\end{aligned}
$$

More Useful Combinators

$<??>$

$$p <??> q :: Parser\ s\ a \rightarrow Parser\ s\ (a \rightarrow a) \rightarrow Parser\ s\ a$$
$$p <??> q = p <**> (q\ `opt`\ id)$$

More Useful Combinators

$<??>$

$$p <??> q :: Parser\ s\ a \rightarrow Parser\ s\ (a \rightarrow a) \rightarrow Parser\ s\ a$$
$$p <??> q = p <**> (q\ `opt`\ id)$$

$pParens$

$$pParens :: s \rightarrow s \rightarrow Parser\ s\ a \rightarrow Parser\ s\ a$$
$$pParens\ l\ r = pSym\ l\ \ *>\ x <*\ \ pSym\ r$$

Left Factorisation II

We want to recognise expressions with as result a value of the type:

$$
\begin{array}{lllll}
\textbf{data}\ \mathit{Expr} = & \mathit{Lambda} & \mathit{Id} & \mathit{Expr} \\
\quad\quad\quad\quad\ \mid & \mathit{App} & \mathit{Expr} & \mathit{Expr} \\
\quad\quad\quad\quad\ \mid & \mathit{TypedExpr} & \mathit{TypeDescr} & \mathit{Expr}
\end{array}
$$

Left Factorisation II

We want to recognise expressions with as result a value of the type:

```
data Expr = Lambda     Id          Expr
          | App        Expr        Expr
          | TypedExpr  TypeDescr   Expr
```

```
pFactor =      Lambda <$  pSym '\\' <*> pIdent <*> pExpr
          <|> pParens '(' ')' pExpr
```

Left Factorisation II

We want to recognise expressions with as result a value of the type:

```
data Expr = Lambda     Id          Expr
          | App        Expr        Expr
          | TypedExpr  TypeDescr   Expr
```

```
pFactor =      Lambda <$  pSym '\\' <*> pIdent <*> pExpr
          <|> pParens '(' ')' pExpr
```

```
pExpr =      pChainl (pSucceed App) pFactor
        <??> (     TypedExpr
              <$  pTok "::"
              <*> pTypeDescr
             )
```

Chain Parsers

A nicer definition for *pChainr* is:

$$pChainr\ sep\ p = p <??> (flip <\$> sep <*> pChainr\ sep\ p)$$

1.5 Monadic Parsers

The Chomsky Hierarchy

§1.5

The Chomsky hierarchy:

- Regular
- Context-free
- Context-sensitive
- Recursively enumerable

It is well known that context free grammars have limited expressibility.

Recognising $\{a^n b^n c^n\}$

$$
\begin{aligned}
&\mathit{times} && :: \mathit{Int} \rightarrow \mathit{Parser\ Char\ a} \rightarrow \mathit{Parser\ Char\ a} \\
&0\ \text{`}\mathit{times}\text{`}\ p && = \mathit{pSucceed}\ [\,] \\
&n\ \text{`}\mathit{times}\text{`}\ p && = (:)\ \langle\$\rangle\ p\ \langle*\rangle\ (n-1)\ \text{`}\mathit{times}\text{`}\ p
\end{aligned}
$$

Recognising $\{a^n b^n c^n\}$

$$
\begin{aligned}
&< *(n`times`b) < *(n`times`c) < *(n`times`b) < \\
&\quad times && :: Int \rightarrow Parser\ Char\ a \rightarrow Parser\ Char\ a \\
&\quad 0\ `times`\ p && = pSucceed\ [\,] \\
&*(n`times`c)n\ `times`\ p && = (:) <\$> p <*> (n-1)\ `times`\ p \\
&\quad abc\ n && = n <\$\ \ (n\ `times`\ a)
\end{aligned}
$$

Recognising $\{a^n b^n c^n\}$

$$
\begin{aligned}
< *(n`times`b) < *(n`times`c) < *(n`times`b) < \\
times \quad & :: Int \to Parser\ Char\ a \to Parser\ Char\ a \\
0\ `times`\ p &= pSucceed\ [\,] \\
(n`times`c)n\ `times`\ p &= (:) <\$> p <> (n-1)\ `times`\ p \\
abc\ n \quad & = n <\$\ \ (n\ `times`\ a) \\
ABC \quad & = foldr\ (<|>)\ pFail\ [abc\ n \mid n \leftarrow 0\,..]
\end{aligned}
$$

Recognising $\{a^n b^n c^n\}$

$$
\begin{aligned}
< *(n`times`b) < *(n`times`c) < *(n`times`b) < \\
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0\ `times`\ p & = pSucceed\ [\,] \\
(n`times`c)n\ `times`\ p & = (:) <\$> p <> (n-1)\ `times`\ p \\
abc\ n & = n <\$\ \ (n\ `times`\ a) \\
ABC & = foldr\ (<|>)\ pFail\ [abc\ n \mid n \leftarrow 0\,..]
\end{aligned}
$$

We admit that this is not very efficient, but left factorisation is not so easy since the corresponding context free grammar is infinite.

Recognising $\{a^n b^n c^n\}$: The Monadic Approach

§1.5

Wouldn't it be nice if we could start by just recognizing a sequence of a s, and then use the result to enforce the right number of b s and c s?

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$$
\begin{array}{l}
\textbf{instance}\ \mathit{Monad}\ (\mathit{Parser}\ s)\ \textbf{where} \\
\quad p\ (\gg\!=)\ q = \lambda inp \rightarrow [\,(qv, rr) \mid (pv, r) \leftarrow p\ \ inp \\
\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad , (qv, rr) \leftarrow q\ pv\ r \\
\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad] \\
\quad return\ v \quad = \lambda inp \rightarrow [\,(v, inp)\,]
\end{array}
$$

Recognising $\{a^n b^n c^n\}$: The Monadic Approach

§1.5

Wouldn't it be nice if we could start by just recognizing a sequence of a s, and then use the result to enforce the right number of b s and c s?

```
instance Monad (Parser s) where
  p (>>=) q = λinp → [(qv, rr) | (pv, r) ← p inp
                               , (qv, rr) ← q pv r
                               ]
  return v  = λinp → [(v, inp)]
as          :: Parser Char Int
as          = length <$ pList (pSym 'a')
bc n        = n <$ (n `times` b) <* (n `times` c)
```

Recognising $\{a^n b^n c^n\}$: The Monadic Approach

§1.5

Wouldn't it be nice if we could start by just recognizing a sequence of a s, and then use the result to enforce the right number of b s and c s?

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instance Monad (Parser s) where
  p (>>=) q = λinp → [(qv, rr) | (pv, r) ← p inp
                               , (qv, rr) ← q pv r
                               ]
  return v  = λinp → [(v, inp)]
as          :: Parser Char Int
as          = length <$ pList (pSym 'a')
bc n        = n <$ (n `times` b) <* (n `times` c)
ABC         = do n ← as
                 bc n
```

Intersection of Languages

§1.5

Can we achieve the same effect by using :
$\{a^n b^n c^n\} = \{a^i b^j c^j\} \cap \{a^j b^j c^i\}$?

Intersection of Languages

Can we achieve the same effect by using :
$\{a^n b^n c^n\} = \{a^i b^j c^j\} \cap \{a^j b^j c^i\}$?
We redefine the type *Parser* to keep track of the length of the recognized part:

$$
\begin{aligned}
&\textbf{type}\ \mathit{Parser}\ s\ a = [s] \rightarrow [(a, [s], \mathit{Int})]] \\
&(p \langle * \rangle q)\ \mathit{inp} \quad = [\,(pv\ qv, rr, pc + qc) \mid (pv, r,\ pc) \leftarrow p\ \mathit{inp} \\
&\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad , (qv, rr, qc) \leftarrow q\ r \\
&\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad] \\
&\ldots
\end{aligned}
$$

Continued ..

```
(<&&>) :: Parser s a → Parser s b → Parser s (a, b)
(p <&&> q) inp = [((pv, qv), r, pc) | (pv, r, pc) ← p inp
                                    , (qv, _, qc) ← q inp
                                    , pc ≡ qc
                 ]
```

```
jj x y = let xy = (2+) <$  pSym x <*> xy <*  pSym y `opt`
i x    = (1+)          <$  pSym x <*> i x `opt` 0
ABC =                (+) <$  i 'a'        <*> jj 'b' 'c'
           <&&>      (+) <$> jj 'a' 'b'   <*> i      'c'
```

1.6 Problems

Problems with Erroneous Input

§1.6

- If your input does not conform to the language recognized by the parser all you get as a result is: $[\,]$.
- It may take quite a while before you get this negative result, since the backtracking may try all other alternatives at all positions.
- There is no indication of where things went wrong.

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- There is no indication of where things went wrong.

These problem have been cured in both Parsec and the UUParsing-library. The latter does this:

- without much overhead
- without need for help from the programmer
- without stopping, so many errors can be found in a single run

Left Recursions

As with any top-down parsing method, having left-recursive parsers is no good

- You get non-terminating parsers
- You get no error messages

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This problem can be partially been cured as we will see later.

Problems with Space Consumption

- The complete input has to be parsed before any result is returned
- The complete input is present in memory as long as no parse has been found
- Efficiency may depend critically on the ordering of the alternatives, and thus on how the grammar was written

For all of these problems we have found solutions.