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In addition to specifying syntactically valid sequences of tokens for language constructs, these BNF or EBNF specifications *also specify what sequences of characters are instances of tokens with multiple instances*:

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But in other BNF and EBNF specifications of programming language syntax the terminals are *characters* and certain ***nonterminals*** are tokens that have multiple instances:

In addition to specifying syntactically valid sequences of tokens for language constructs, these BNF or EBNF specifications *also specify what sequences of characters are instances of tokens with multiple instances*: The commonest examples of such tokens are IDENTIFIER and tokens whose instances are literal constants of some type.

Are Tokens Terminals?

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In addition to specifying syntactically valid sequences of tokens for language constructs, these BNF or EBNF specifications *also specify what sequences of characters are instances of tokens with multiple instances*.

In fact we've already seen an example of the use of BNF to specify such a token:

$$
\begin{aligned}
\langle \textit{real-number} \rangle &::= \langle \textit{integer-part} \rangle \ . \ \langle \textit{fraction} \rangle \\
\langle \textit{integer-part} \rangle &::= \langle \textit{digit} \rangle \mid \langle \textit{integer-part} \rangle \ \langle \textit{digit} \rangle \\
\langle \textit{fraction} \rangle &::= \langle \textit{digit} \rangle \mid \langle \textit{digit} \rangle \ \langle \textit{fraction} \rangle \\
\langle \textit{digit} \rangle &::= 0 \mid 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7 \mid 8 \mid 9
\end{aligned}
$$

Figure 2.3 BNF rules for real numbers.

A grammar given by by Sethi to specify unsigned floating point literals in a simple language.

Example of How to Write a Recursive Descent Parsing Method, and How Such a Method Creates a Parse Tree

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- We will consider how to write a parsing method

  varDecl()

  for the nonterminal defined by this EBNF rule:

```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl> } ;
            | Scanner IDENTIFIER = new Scanner '(' System . in ')' ;
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Example of How to Write a Recursive Descent Parsing Method, and How Such a Method Creates a Parse Tree

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```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl> } ;
            | Scanner IDENTIFIER = new Scanner '(' System . in ')' ;
```

- We will also look at how the method reads a syntactically valid <varDecl> and outputs a sideways parse tree of its sequence of tokens.

```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
           |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```

```
private static void varDecl() throws SourceFileErrorException
{
  TJ.output.printSymbol(NTvarDecl); TJ.output.incTreeDepth();

  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA) {
      nextToken();
      singleVarDecl();
    }
    accept(SEMICOLON);
  }
  else if (getCurrentToken() == SCANNER) {
    nextToken();

    if (getCurrentToken() == IDENT) nextToken();
    else throw new SourceFileErrorException("Scanner name expected");

    accept(BECOMES); accept(NEW); accept(SCANNER);
    accept(LPAREN); accept(SYSTEM); accept(DOT);
    accept(IN);  accept(RPAREN); accept(SEMICOLON);
  }
  else throw new SourceFileErrorException("\"int\" or \"Scanner\" expected");

  TJ.output.decTreeDepth();
}
```

```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
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private static void varDecl() throws SourceFileErrorException
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```

```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;

private static void varDecl() throws SourceFileErrorException
{
  TJ.output.printSymbol(NTvarDecl); TJ.output.incTreeDepth();
  if (getCurrentToken() == INT) {









  }
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  else throw new SourceFileErrorException("\"int\" or \"Scanner\" expected");
  TJ.output.decTreeDepth();
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<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
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{
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  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();





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{
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  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA) {



    }

  }
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    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA) {
      nextToken();

    }

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    while (getCurrentToken() == COMMA) {
      nextToken();
      singleVarDecl()
    }

  }
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    while (getCurrentToken() == COMMA) {
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    }
    accept(SEMICOLON);
  }
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  TJ.output.printSymbol(NTvarDecl); TJ.output.incTreeDepth();

  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA != SEMICOLON) {  // ALTERNATIVE CODE
      nextToken(); accept(COMMA);
      singleVarDecl();
    }
    accept(SEMICOLON);
  }
  else if (getCurrentToken() == SCANNER) {









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    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA != SEMICOLON) {  // ALTERNATIVE CODE
      nextToken(); accept(COMMA);
      singleVarDecl();
    }
    accept(SEMICOLON); nextToken();                    // OPTIONAL CHANGE
  }
  else if (getCurrentToken() == SCANNER) {









  }
  else throw new SourceFileErrorException("\"int\" or \"Scanner\" expected");

  TJ.output.decTreeDepth();
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    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA) {
      nextToken();
      singleVarDecl();
    }
    accept(SEMICOLON);
  }
  else if (getCurrentToken() == SCANNER) {
    nextToken();

    accept(IDENT);  // This is OK, but if currentToken != IDENT then the
                    // “Something’s wrong” error message is not very nice!




  }
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```
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    }
    accept(SEMICOLON);
  }
  else if (getCurrentToken() == SCANNER) {
    nextToken();

    if (getCurrentToken() == IDENT) nextToken(); // better than accept(IDENT);
    else throw new SourceFileErrorException("Scanner name expected");




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}
```

Creation of Sideways Parse Tree of `int w, x = 17, y[], z;` **with root** `<varDecl>`

Based on `<varDecl> ::= int <singleVarDecl> { , <singleVarDecl>} ;`
`| Scanner IDENTIFIER = new Scanner '(' System . in ')' ;`

```
<varDecl>
 Reserved Word: int
 <singleVarDecl>
  IDENTIFIER: w
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: x
  =
  <expr3>
   <expr2>
    <expr1>
     UNSIGNED INTEGER LITERAL: 17
     ... node has no more children
    ... node has no more children
   ... node has no more children
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: y
  [
  ]
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: z
  ... node has no more children
 ;
 ... node has no more children
```

Creation of Sideways Parse Tree of `int w, x = 17, y[], z;` **with root** `<varDecl>`

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 ,
 <singleVarDecl>
  IDENTIFIER: x
  =
  <expr3>
   <expr2>
    <expr1>
     UNSIGNED INTEGER LITERAL: 17
     ... node has no more children
    ... node has no more children
   ... node has no more children
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: y
  [
  ]
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: z
  ... node has no more children
 ;
 ... node has no more children
```

```
private static void varDecl()
        throws SourceFileErrorException
{
  TJ.output.printSymbol(NTvarDecl);
  TJ.output.incTreeDepth();

  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA) {
      nextToken();
      singleVarDecl();
    }
    accept(SEMICOLON);
  }
  else if (getCurrentToken()==SCANNER) {
                ...
  }
  else
    throw new SourceFileErrorException
      ("\"int\" or \"Scanner\" needed");

  TJ.output.decTreeDepth();
}
```

Creation of Sideways Parse Tree of int w, x = 17, y[], z; **with root** <varDecl>

Based on <varDecl> **::= int** <singleVarDecl> **{ ,** <singleVarDecl>**}** ;

| **Scanner** IDENTIFIER = **new Scanner** '(' **System . in** ')' ;

```
private static void varDecl()
        throws SourceFileErrorException
{

}
```

Creation of Sideways Parse Tree of `int w, x = 17, y[], z;` **with root** `<varDecl>`

Based on `<varDecl> ::= int <singleVarDecl> { , <singleVarDecl>} ;`

`| Scanner IDENTIFIER = new Scanner '(' System . in ')' ;`

<varDecl>

```
private static void varDecl()
        throws SourceFileErrorException
{
  TJ.output.printSymbol(NTvarDecl);

}
```

Creation of Sideways Parse Tree of `int w, x = 17, y[], z;` **with root** `<varDecl>`

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... node has no more children

Creation of Sideways Parse Tree of `int w, x = 17, y[], z;` **with root** `<varDecl>`

Based on `<varDecl> ::= int <singleVarDecl> { , <singleVarDecl>} ;`

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<varDecl>

```
private static void varDecl()
        throws SourceFileErrorException
{
  TJ.output.printSymbol(NTvarDecl);
  TJ.output.incTreeDepth();

  if (getCurrentToken() == INT) {





  }
  else if


  else



  TJ.output.decTreeDepth();
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Creation of Sideways Parse Tree of `int w, x = 17, y[], z;` **with root** `<varDecl>`

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```
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  TJ.output.incTreeDepth();
  if (getCurrentToken() == INT) {





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Creation of Sideways Parse Tree of int w, x = 17, y[], z; **with root** <varDecl>

Based on <varDecl> ::= int <singleVarDecl> { , <singleVarDecl>} ;

| **Scanner** IDENTIFIER = **new Scanner** '(' **System** . **in** ')' ;

<varDecl>

Reserved Word: int

```
private static void varDecl()
        throws SourceFileErrorException
{
  TJ.output.printSymbol(NTvarDecl);
  TJ.output.incTreeDepth();

  if (getCurrentToken() == INT) {
    nextToken();




  }
  else if


  else


  TJ.output.decTreeDepth();
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Creation of Sideways Parse Tree of int w, x = 17, y[], z; **with root** <varDecl>

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| **Scanner** IDENTIFIER = **new Scanner** '(' **System** . **in** ')' ;

<varDecl>
Reserved Word: int
<singleVarDecl>
IDENTIFIER: w
... node has no more children

```
private static void varDecl()
        throws SourceFileErrorException
{
  TJ.output.printSymbol(NTvarDecl);
  TJ.output.incTreeDepth();

  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();




  }
  else if


  else



  TJ.output.decTreeDepth();
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Creation of Sideways Parse Tree of int w, x = 17, y[], z; **with root** <varDecl>

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```
<varDecl>
 Reserved Word: int
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  IDENTIFIER: w
  ... node has no more children
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private static void varDecl()
        throws SourceFileErrorException
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  TJ.output.printSymbol(NTvarDecl);
  TJ.output.incTreeDepth();

  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA) {


    }

  }
  else if


  else



  TJ.output.decTreeDepth();
}
```

... node has no more children

Creation of Sideways Parse Tree of int w, x = 17, y[], z; **with root** <varDecl>

Based on <varDecl> ::= int <singleVarDecl> { , <singleVarDecl>} ;
| **Scanner** IDENTIFIER = **new Scanner** '(' **System** . **in** ')' ;

<varDecl>
Reserved Word: int
<singleVarDecl>
IDENTIFIER: w
... node has no more children
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  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();
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    }

  }
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Creation of Sideways Parse Tree of int w, x = 17, y[], z; **with root** <varDecl>

Based on <varDecl> ::= int <singleVarDecl> { , <singleVarDecl>} ;
| **Scanner** IDENTIFIER = **new Scanner** '(' **System** . **in** ')' ;

```
<varDecl>
 Reserved Word: int
 <singleVarDecl>
  IDENTIFIER: w
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: x
  =
  <expr3>
   <expr2>
    <expr1>
     UNSIGNED INTEGER LITERAL: 17
     ... node has no more children
    ... node has no more children
   ... node has no more children
  ... node has no more children
```

```
private static void varDecl()
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  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA) {
      nextToken();
      singleVarDecl();
    }

  }
  else if


  else



  TJ.output.decTreeDepth();
}
```

... node has no more children

Creation of Sideways Parse Tree of int w, x = 17, y[], z; **with root** <varDecl>

Based on <varDecl> ::= int <singleVarDecl> { , <singleVarDecl>} ;
| **Scanner** IDENTIFIER = **new Scanner** '(' **System** . **in** ')' ;

```
<varDecl>
 Reserved Word: int
 <singleVarDecl>
  IDENTIFIER: w
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: x
  =
  <expr3>
   <expr2>
    <expr1>
     UNSIGNED INTEGER LITERAL: 17
     ... node has no more children
    ... node has no more children
   ... node has no more children
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: y
  [
  ]
  ... node has no more children
 ... node has no more children
```

```
private static void varDecl()
        throws SourceFileErrorException
{
  TJ.output.printSymbol(NTvarDecl);
  TJ.output.incTreeDepth();

  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA) {
      nextToken();
      singleVarDecl();
    }

  }
  else if


  else



  TJ.output.decTreeDepth();
}
```

Creation of Sideways Parse Tree of int w, x = 17, y[], z; **with root** <varDecl>

Based on <varDecl> ::= int <singleVarDecl> { , <singleVarDecl> } ;
| **Scanner** IDENTIFIER = **new Scanner** '(' **System** . **in** ')' ;

```
<varDecl>
 Reserved Word: int
 <singleVarDecl>
  IDENTIFIER: w
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: x
  =
  <expr3>
   <expr2>
    <expr1>
     UNSIGNED INTEGER LITERAL: 17
     ... node has no more children
    ... node has no more children
   ... node has no more children
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: y
  [
  ]
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: z
  ... node has no more children

 ... node has no more children
```

```
private static void varDecl()
        throws SourceFileErrorException
{
  TJ.output.printSymbol(NTvarDecl);
  TJ.output.incTreeDepth();

  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA) {
      nextToken();
      singleVarDecl();
    }

  }
  else if


  else


  TJ.output.decTreeDepth();
}
```

Creation of Sideways Parse Tree of int w, x = 17, y[], z; **with root** <varDecl>

Based on <varDecl> ::= int <singleVarDecl> { , <singleVarDecl> } ;
| Scanner IDENTIFIER = new Scanner '(' System . in ')' ;

```
<varDecl>
 Reserved Word: int
 <singleVarDecl>
  IDENTIFIER: w
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: x
  =
  <expr3>
   <expr2>
    <expr1>
     UNSIGNED INTEGER LITERAL: 17
     ... node has no more children
    ... node has no more children
   ... node has no more children
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: y
  [
  ]
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: z
  ... node has no more children
 ;
 ... node has no more children
```

```
private static void varDecl()
        throws SourceFileErrorException
{
  TJ.output.printSymbol(NTvarDecl);
  TJ.output.incTreeDepth();

  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA) {
      nextToken();
      singleVarDecl();
    }
    accept(SEMICOLON);
  }
  else if


  else


  TJ.output.decTreeDepth();
}
```

Creation of Sideways Parse Tree of `int w, x = 17, y[], z;` **with root** `<varDecl>`

Based on `<varDecl> ::= int <singleVarDecl> { , <singleVarDecl>} ;`
`| Scanner IDENTIFIER = new Scanner '(' System . in ')' ;`

```
<varDecl>
 Reserved Word: int
 <singleVarDecl>
  IDENTIFIER: w
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: x
  =
  <expr3>
   <expr2>
    <expr1>
     UNSIGNED INTEGER LITERAL: 17
     ... node has no more children
    ... node has no more children
   ... node has no more children
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: y
  [
  ]
  ... node has no more children
 ,
 <singleVarDecl>
  IDENTIFIER: z
  ... node has no more children
 ;
 ... node has no more children
```

```
private static void varDecl()
        throws SourceFileErrorException
{
  TJ.output.printSymbol(NTvarDecl);
  TJ.output.incTreeDepth();

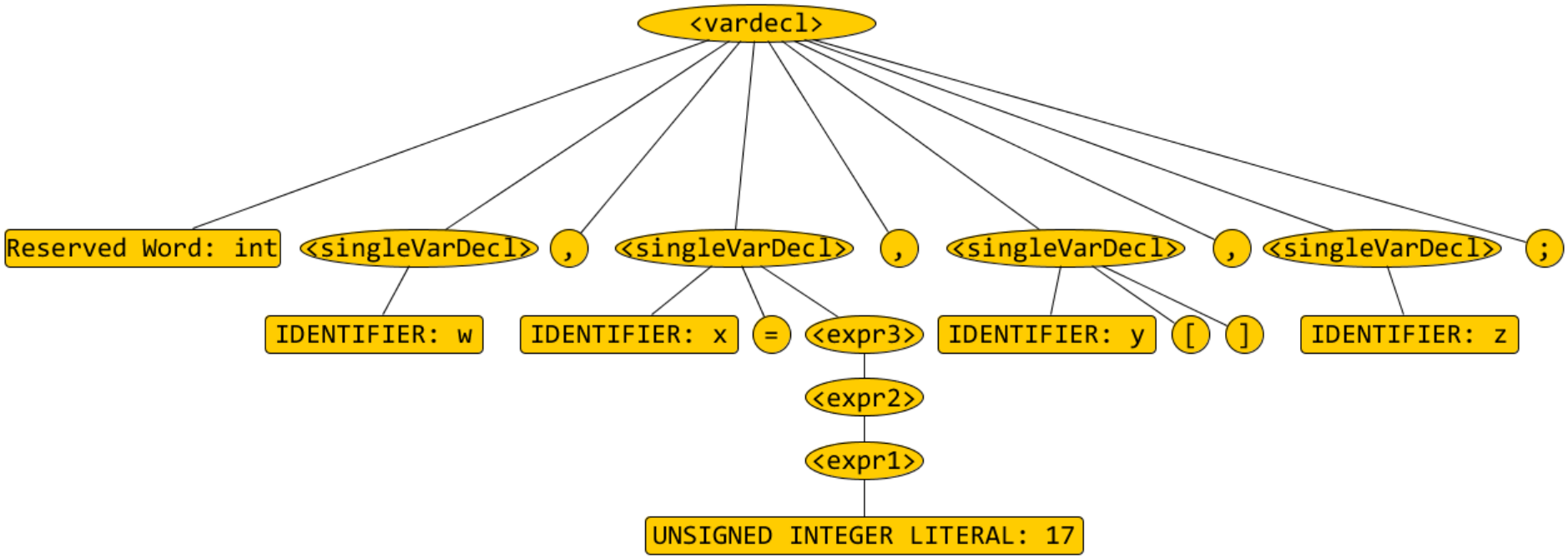
  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA) {
      nextToken();
      singleVarDecl();
    }
    accept(SEMICOLON);
  }
  else if


  else


  TJ.output.decTreeDepth();
}
```

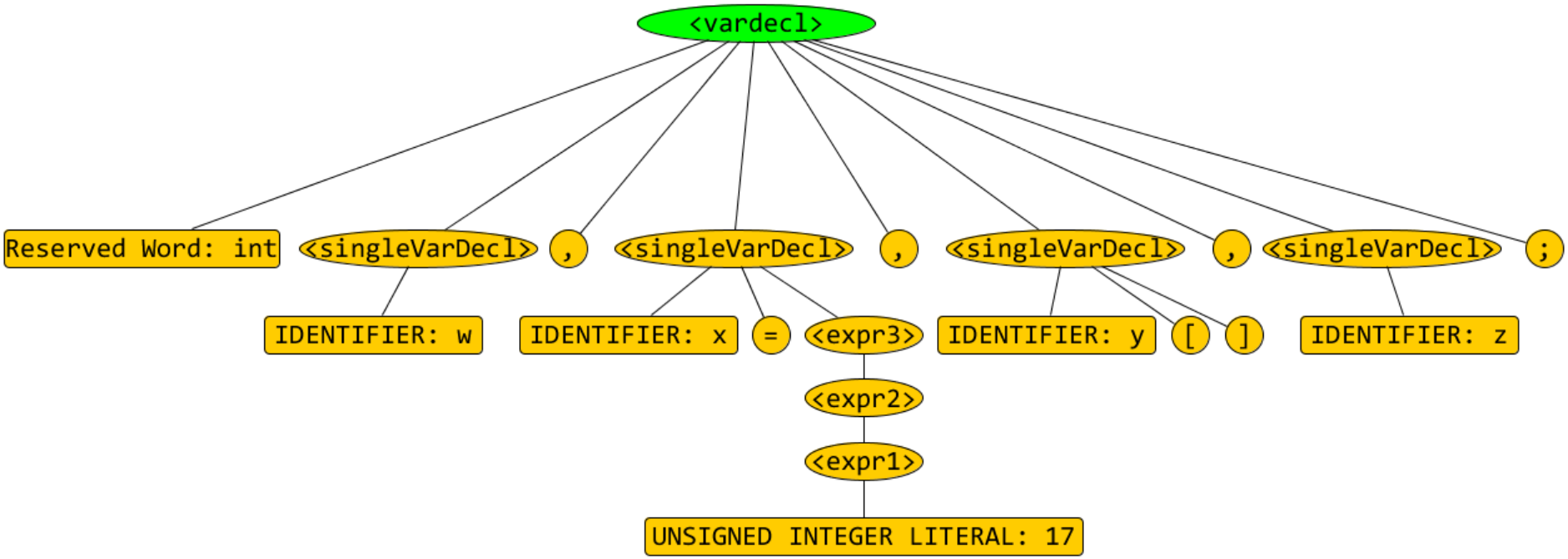
Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

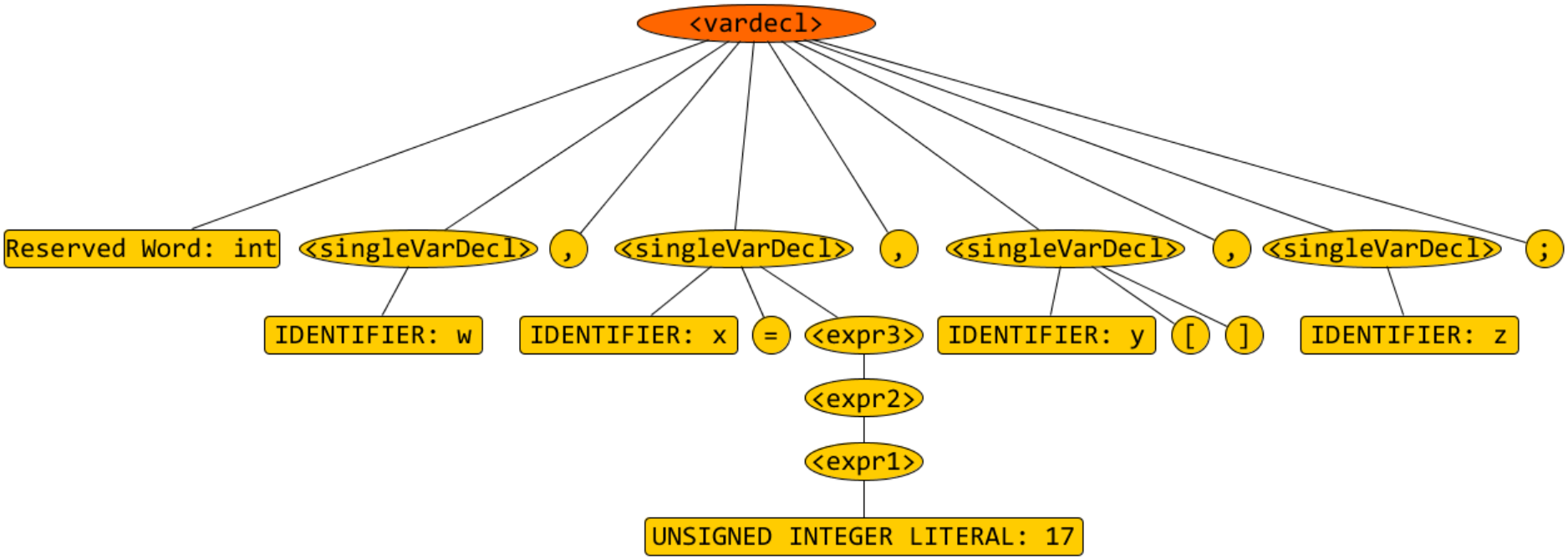
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by: `TJ.output.printSymbol(NTvarDecl);`

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

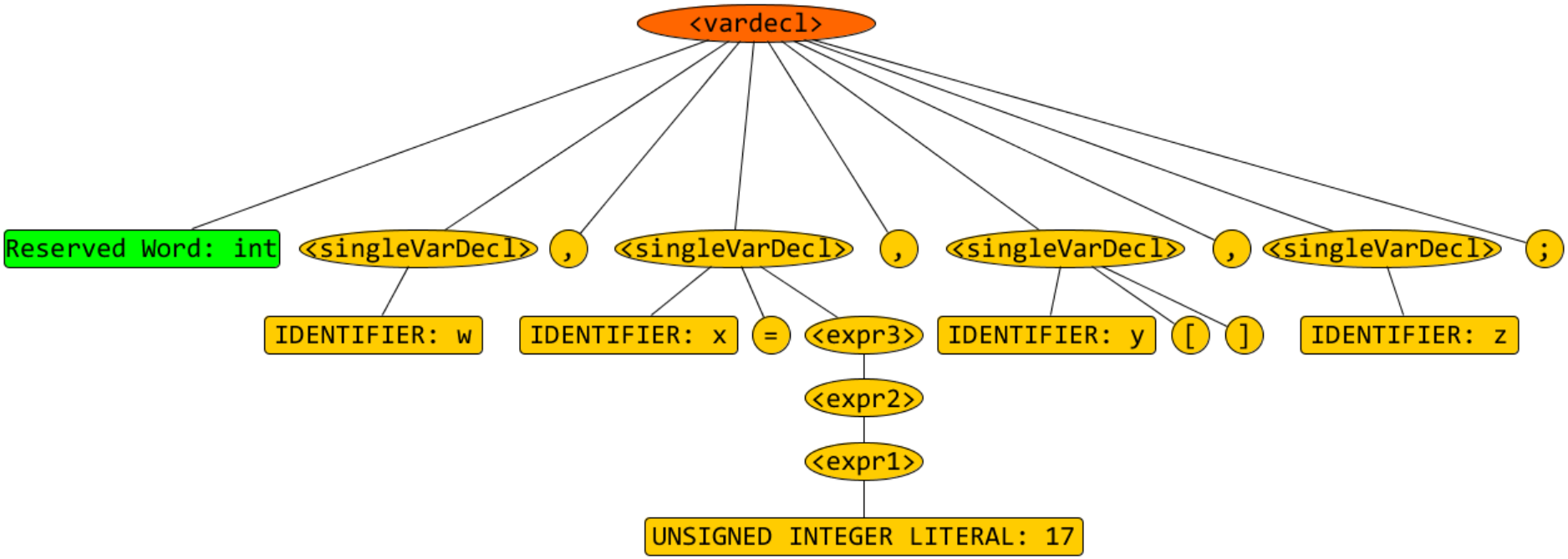
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by:

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

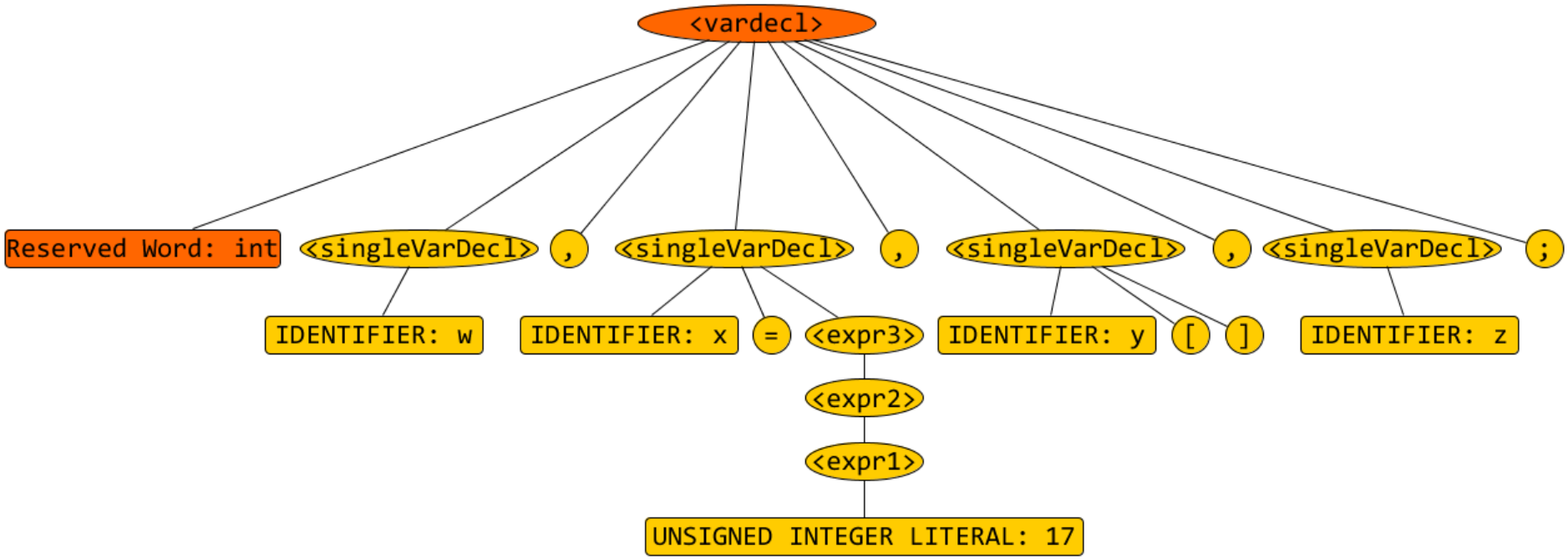
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by: `nextToken();`

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

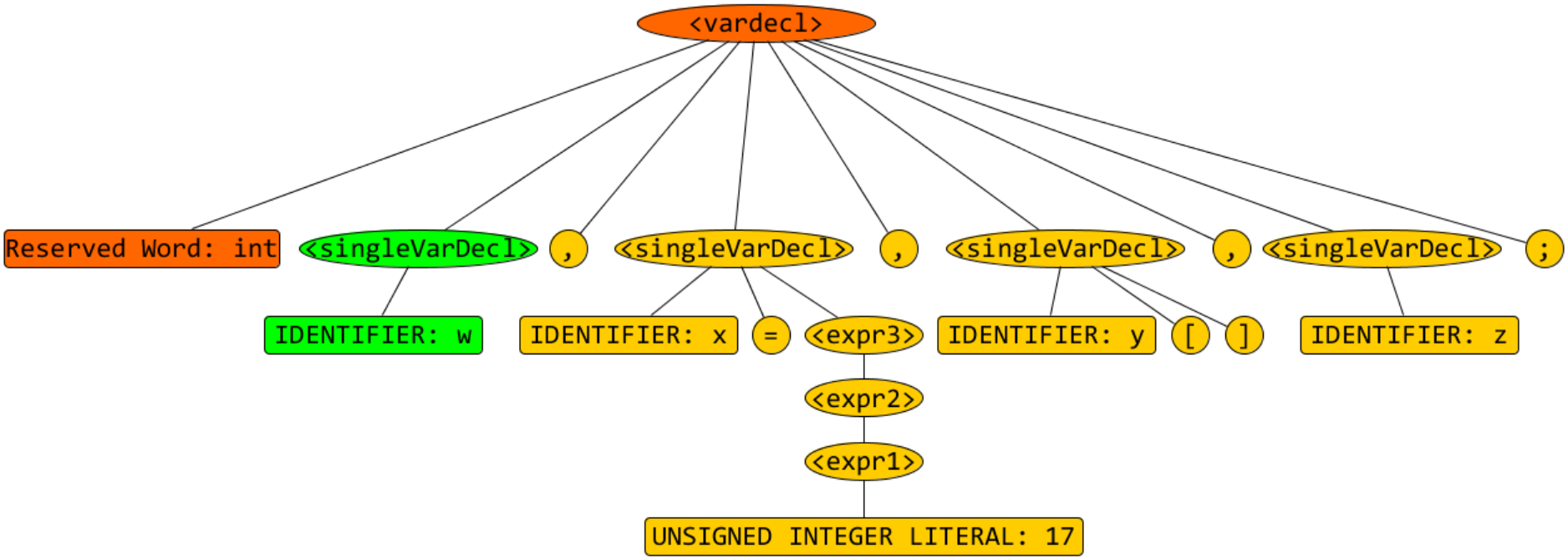
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by:

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

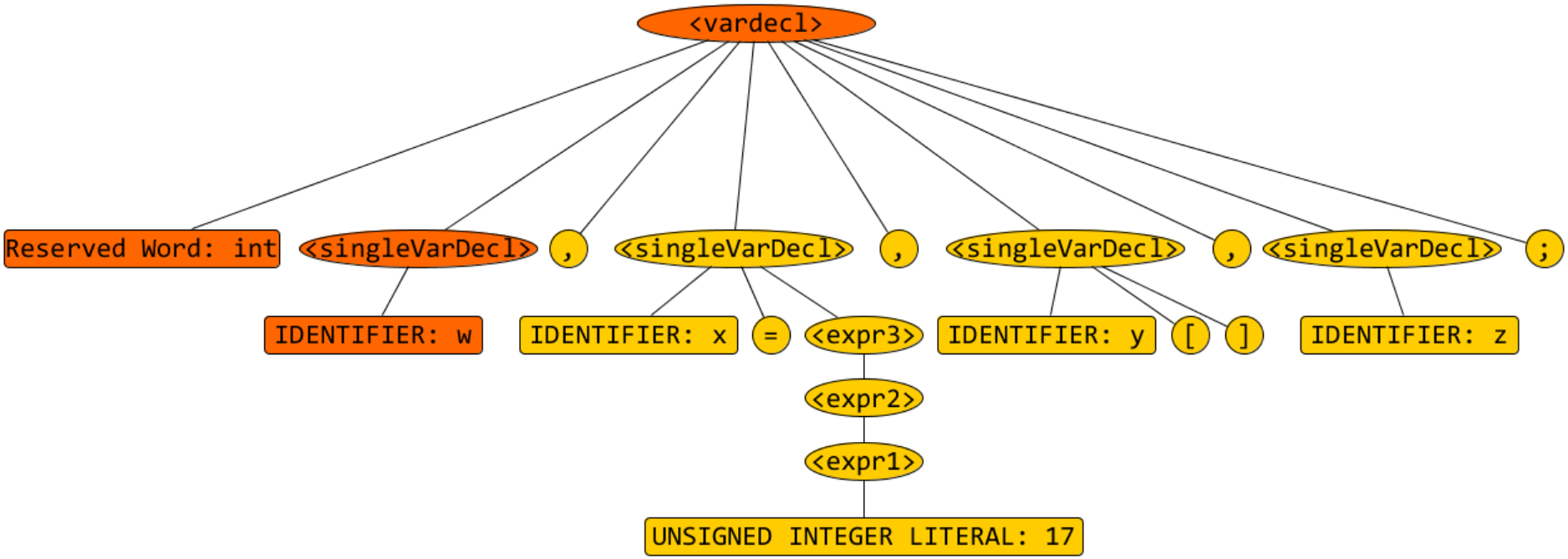
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by: `singleVarDecl();`

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

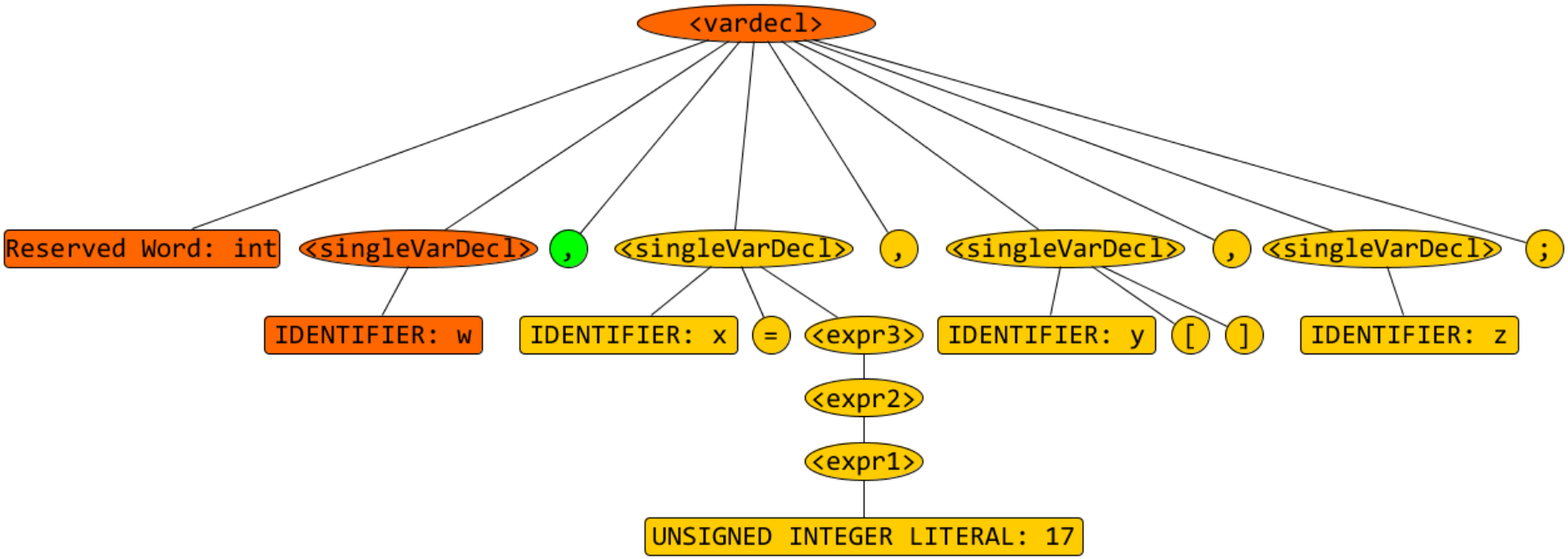
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by:

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

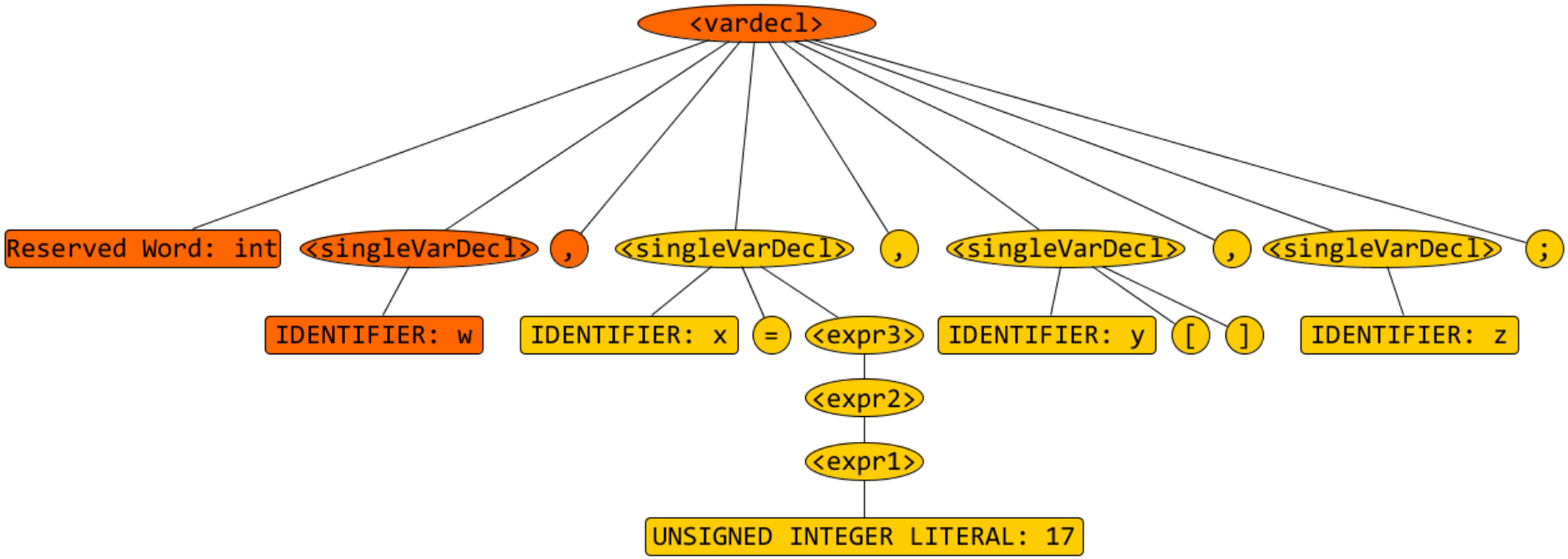
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by: `nextToken();`

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

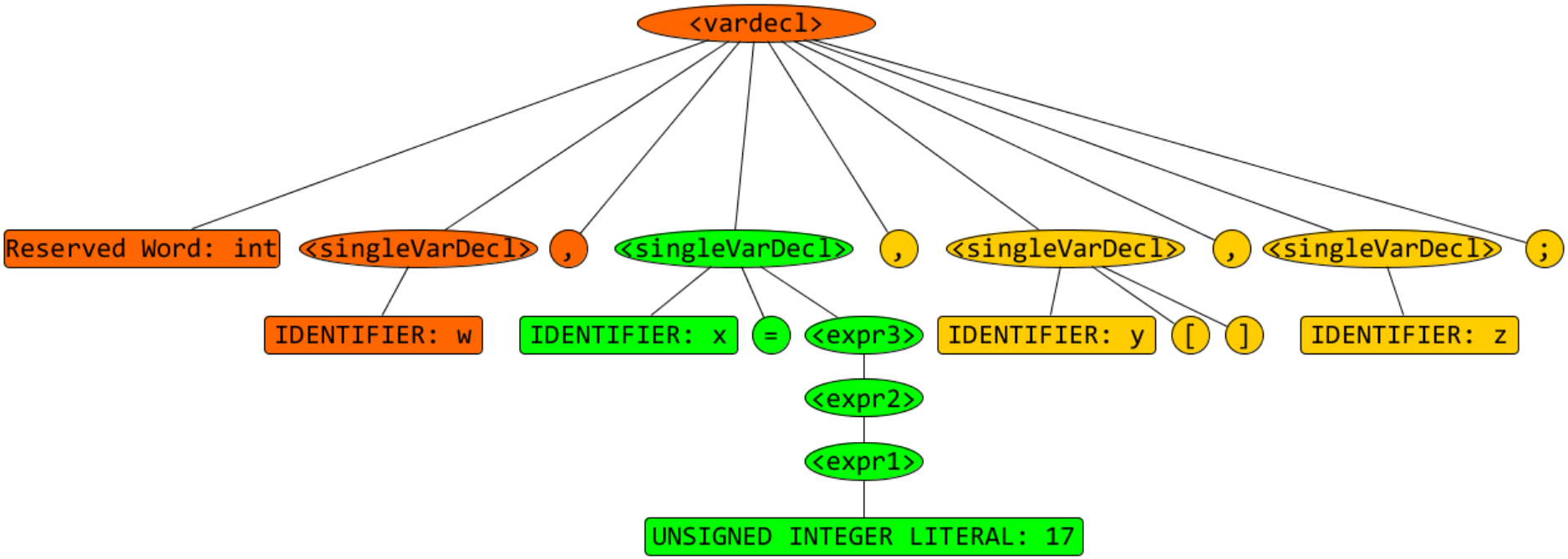
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by:

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

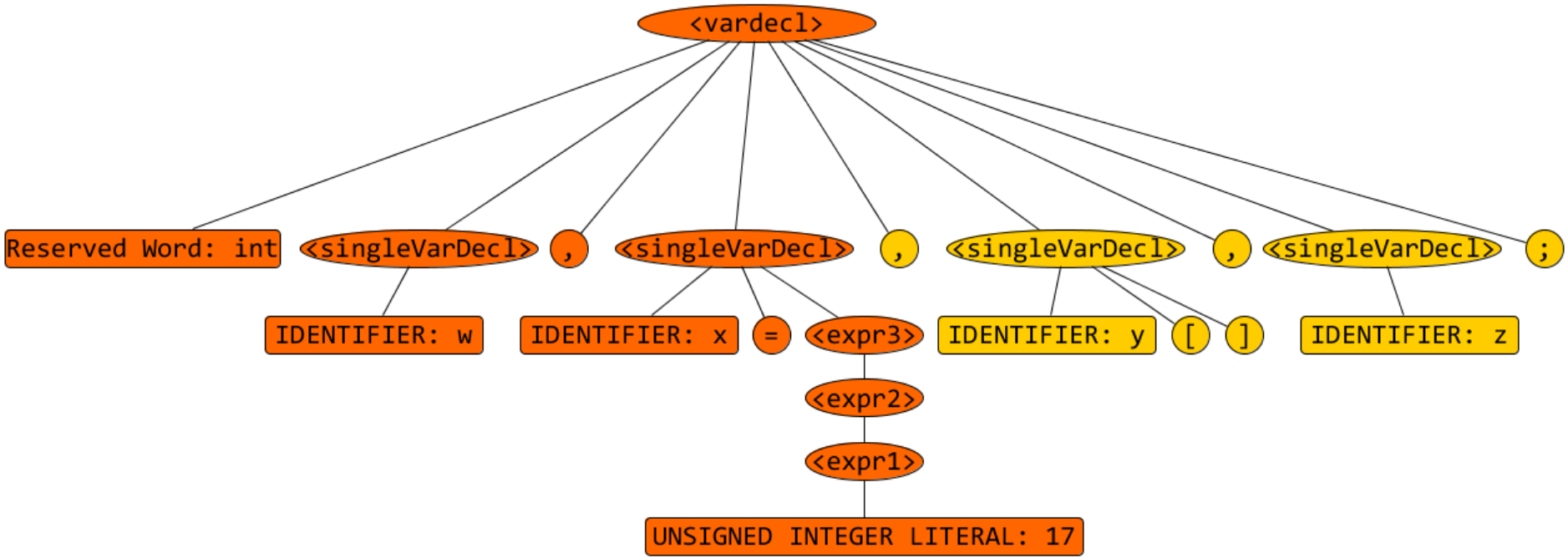
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by: `singleVarDecl();`

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

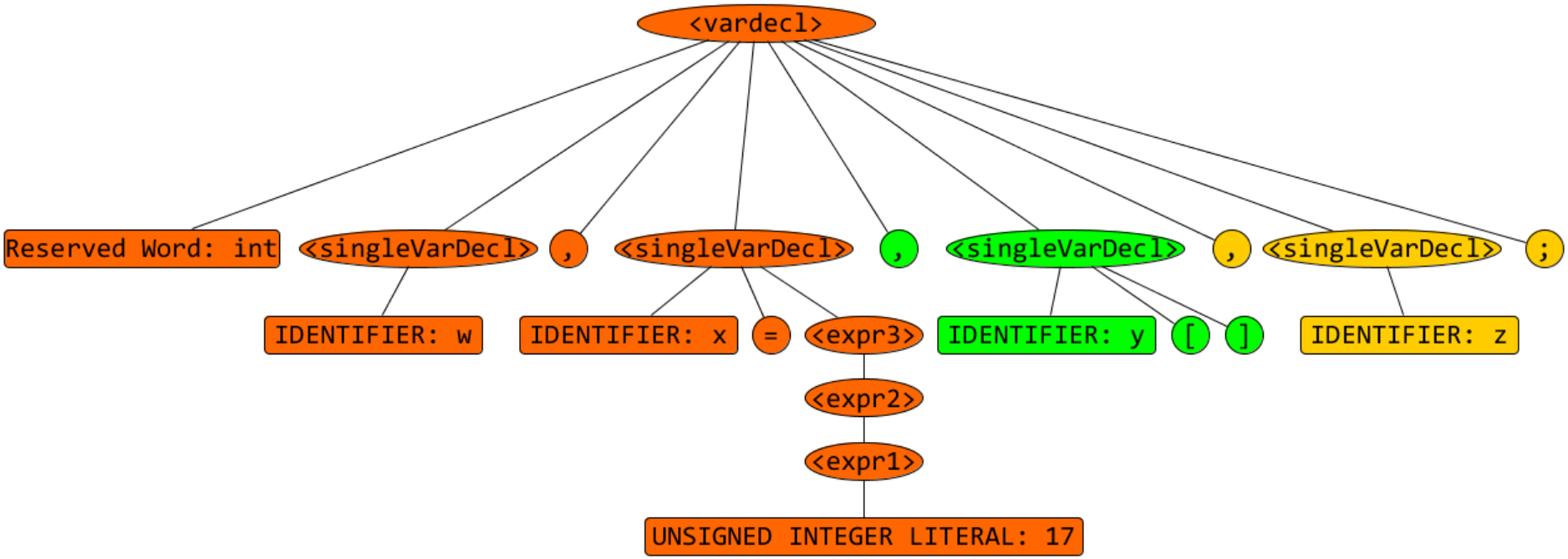
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by:

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

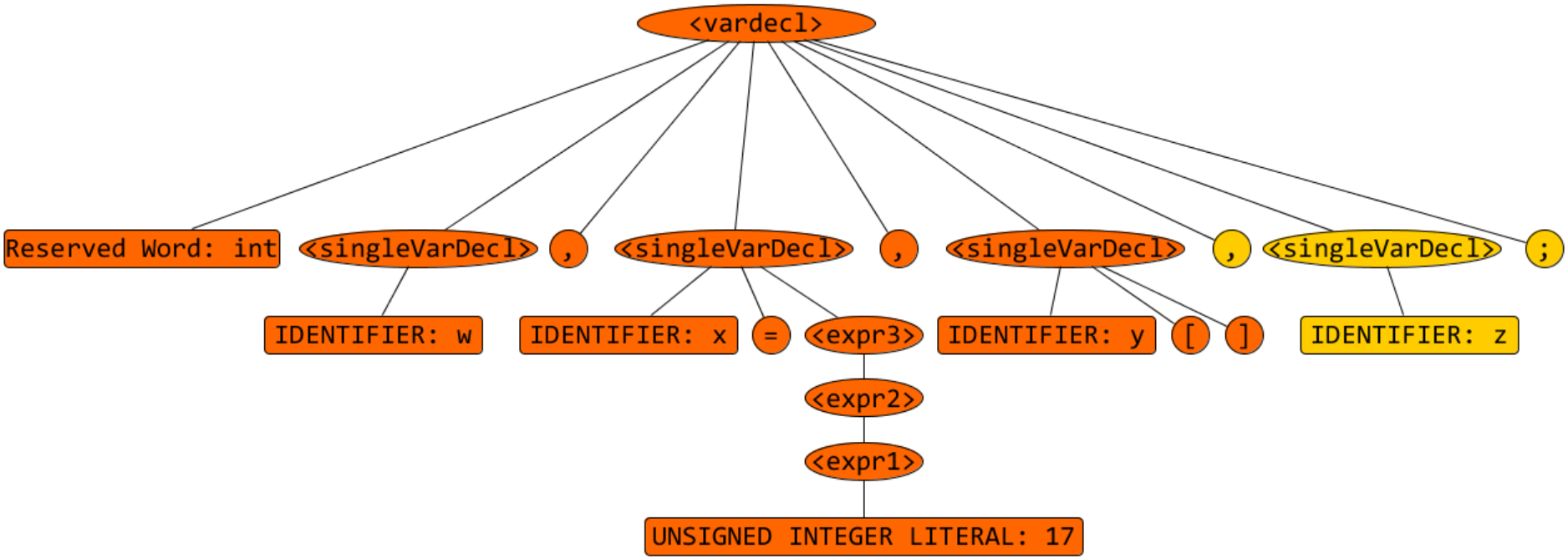
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by: `nextToken(); singleVarDecl();`

Parse tree of int w, x = 17, y[], z;
with root <varDecl>, based on the following EBNF rule:

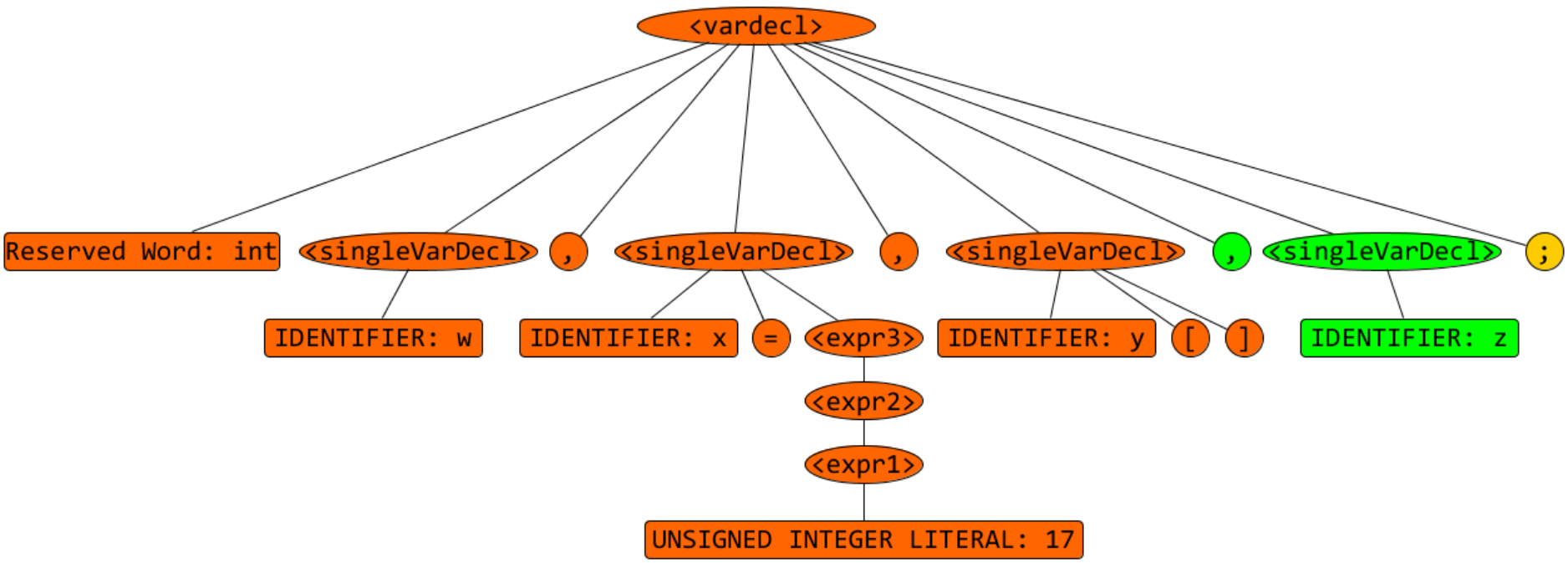
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by:

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

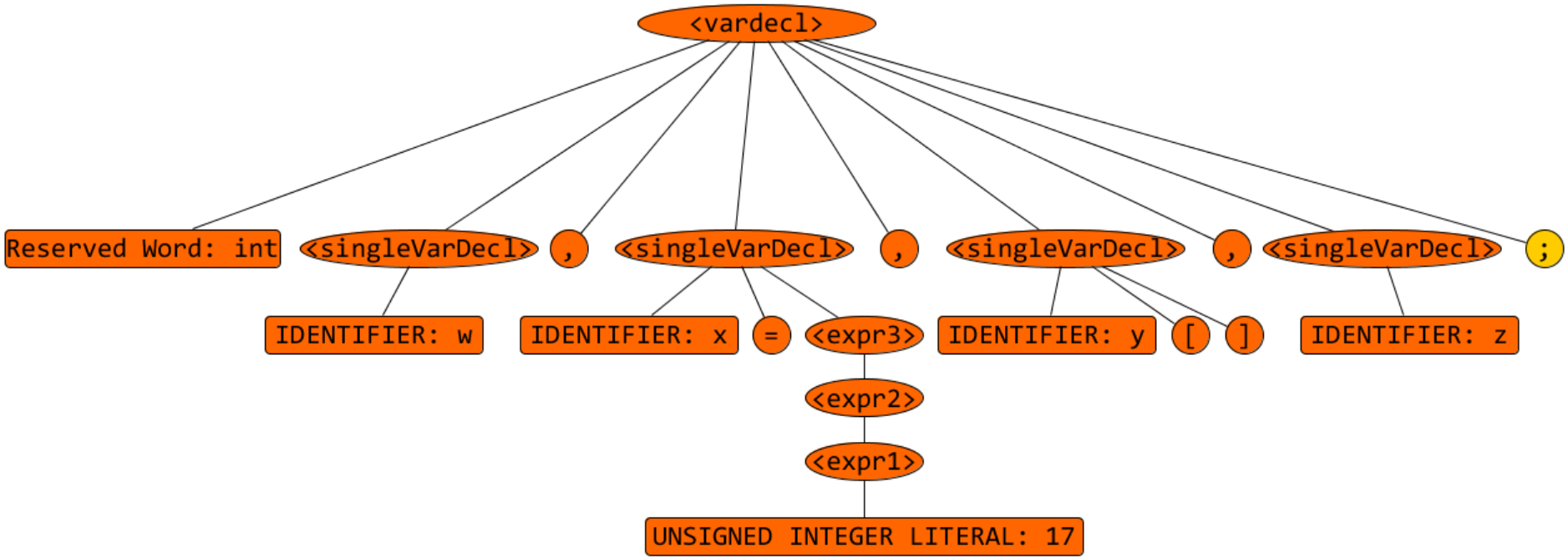
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by: `nextToken(); singleVarDecl();`

Parse tree of int w, x = 17, y[], z;
with root <varDecl>, based on the following EBNF rule:

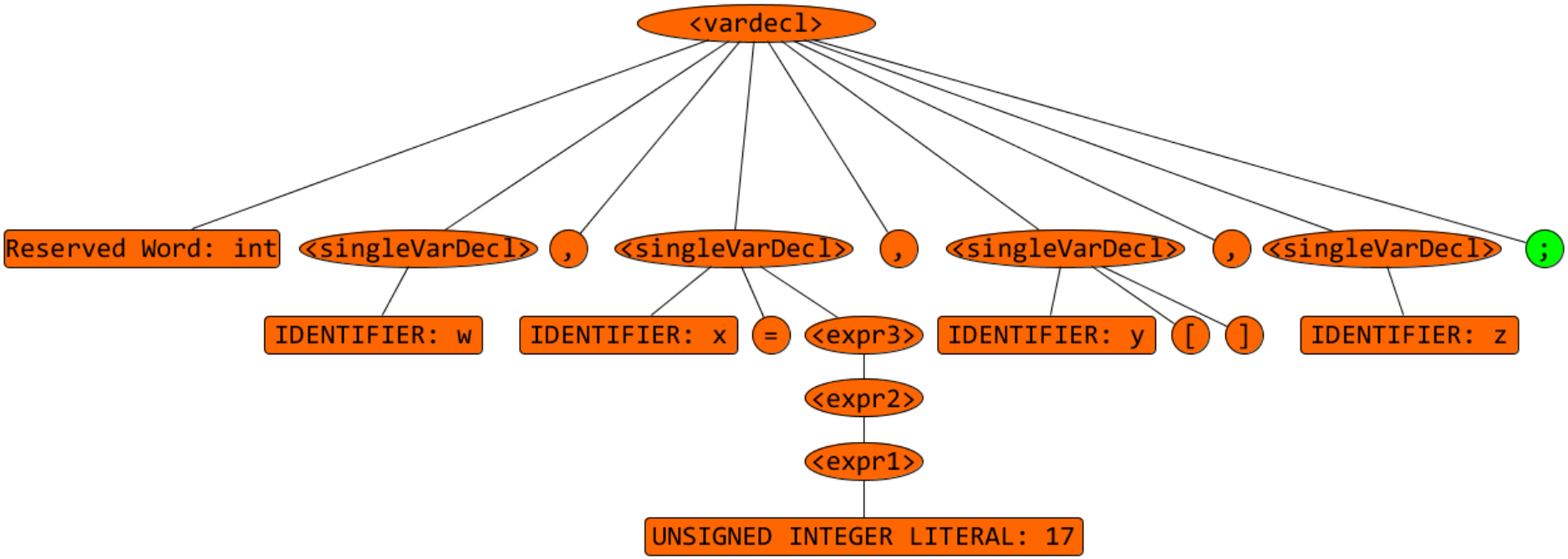
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by:

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

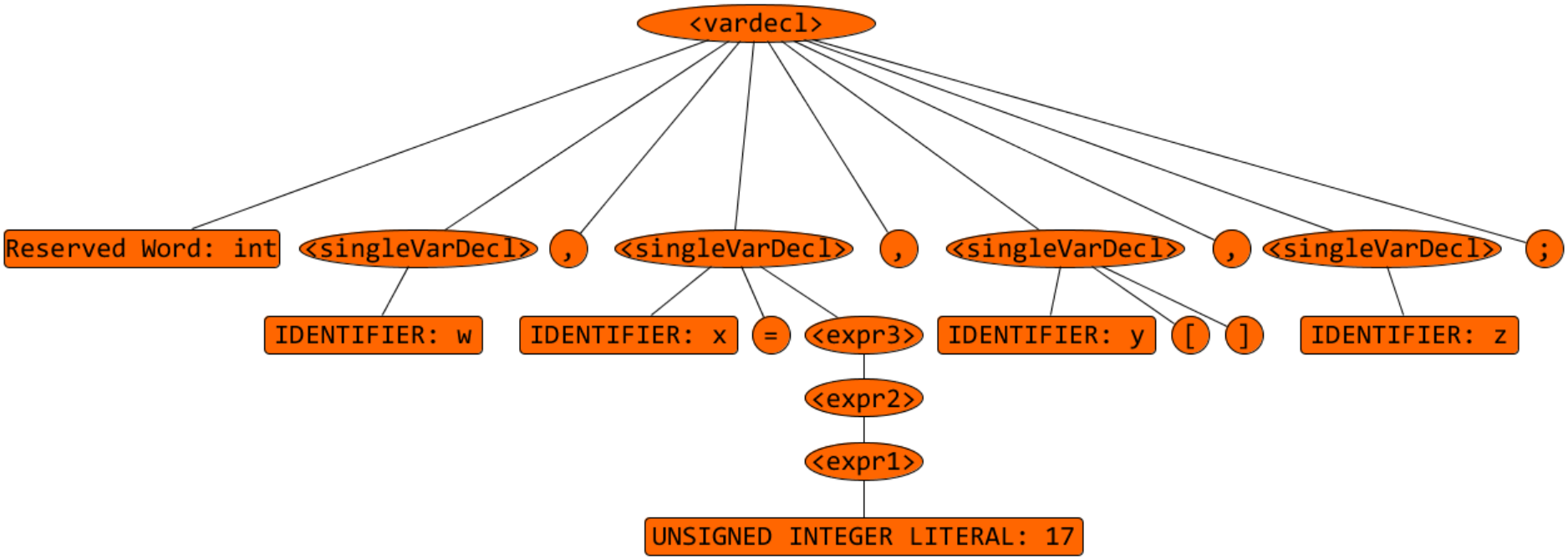
```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



New node(s) created by: `accept(SEMICOLON);`

Parse tree of `int w, x = 17, y[], z;`
with root <varDecl>, based on the following EBNF rule:

```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
            |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```



This is the final tree.

```
<varDecl> ::= int <singleVarDecl> { ,  <singleVarDecl>} ;
           |  Scanner IDENTIFIER = new Scanner '('  System . in  ')' ;
```

```
private static void varDecl() throws SourceFileErrorException
{
  TJ.output.printSymbol(NTvarDecl); TJ.output.incTreeDepth();

  if (getCurrentToken() == INT) {
    nextToken();
    singleVarDecl();
    while (getCurrentToken() == COMMA) {
      nextToken();
      singleVarDecl();
    }
    accept(SEMICOLON);
  }
  else if (getCurrentToken() == SCANNER) {
    nextToken();

    if (getCurrentToken() == IDENT) nextToken();
    else throw new SourceFileErrorException("Scanner name expected");

    accept(BECOMES); accept(NEW); accept(SCANNER);
    accept(LPAREN); accept(SYSTEM); accept(DOT);
    accept(IN);  accept(RPAREN); accept(SEMICOLON);
  }
  else throw new SourceFileErrorException("\"int\" or \"Scanner\" expected");

  TJ.output.decTreeDepth();
}
```