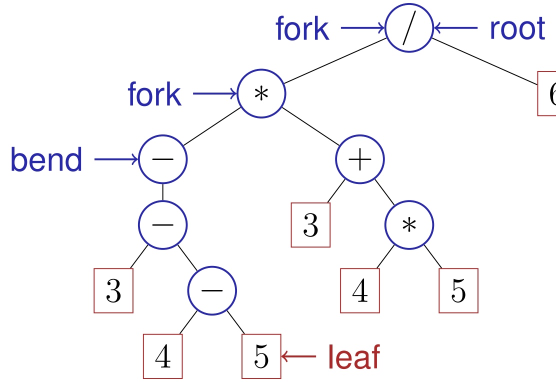
18. Inheritance and Polymorphism

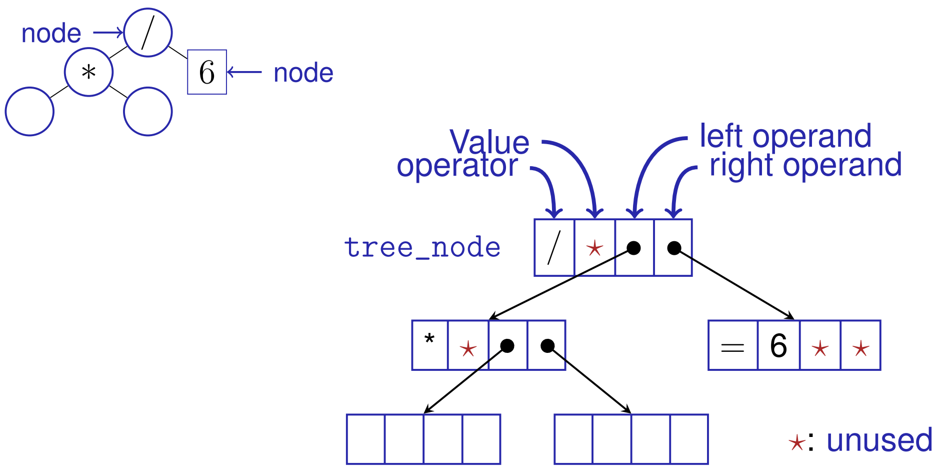
Expression Trees, Inheritance, Code-Reuse, Virtual Functions, Polymorphism, Concepts of Object Oriented Programming

(Expression) Trees

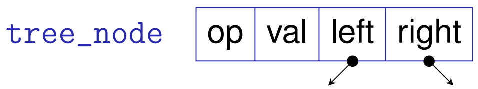
`-(3-(4-5))*(3+4*5)/6`



Nodes: Forks, Bends or Leaves

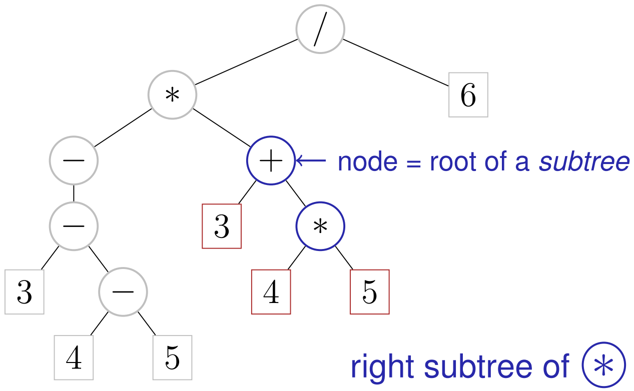


Nodes (`struct tree_node`)

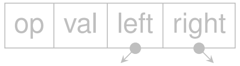



```
struct tree_node {
  char op;
  // leaf node (op: '=')
  double val;
  // internal node ( op: '+', '-', '*', '/')
  tree_node* left; // == 0 for unary minus
  tree_node* right;
  // constructor
  tree_node (char o, double v, tree_node* l, tree_node* r)
    : op (o), val (v), left (l), right (r)
  {}
};
```

Nodes and Subtrees

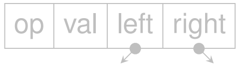


Count Nodes in Subtrees



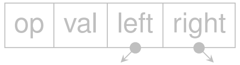

```
struct tree_node {
  ...
   // POST: returns the size (number of nodes) of
   //       the subtree with root *this
   int size () const
   {
       int s=1;
       if (left) // kurz für left != 0
           s += left->size();
       if (right)
           s += right->size();
       return s;
   }
};
```

Evaluate Subtrees



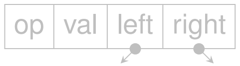

```
struct tree_node {
  ...
  // POST: evaluates the subtree with root *this
  double eval () const {
    if (op == '=') return val;  ← leaf...
    double l = 0;                 ...or fork:
    if (left) l = left->eval(); ← op unary, or left branch
    double r = right->eval();   ← right branch
    if (op == '+') return l + r;
    if (op == '-') return l - r;
    if (op == '*') return l * r;
    if (op == '/') return l / r;
    return 0;
  }
};
```


Cloning Subtrees




```
struct tree_node {
  ...
  // POST: a copy of the subtree with root *this is
  //       made, and a pointer to its root node is
  //       returned
  tree_node* copy () const {
    tree_node* to = new tree_node (op, val, 0, 0);
    if (left)
        to->left = left->copy();
    if (right)
        to->right = right->copy();
    return to;
  }
};
```

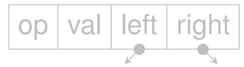
Cloning Subtrees – more Compact Notation



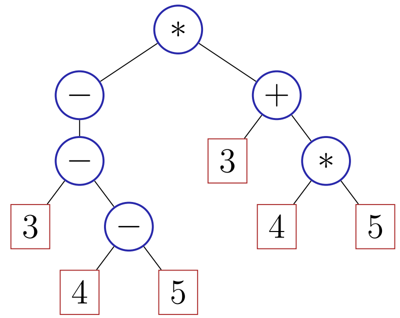

```
struct tree_node {
  ...
  // POST: a copy of the subtree with root *this is
  //       made, and a pointer to its root node is
  //       returned
  tree_node* copy () const {
     return new tree_node (op, val,
            left ? left->copy() : 0,
            right ? right->copy() : 0);
  }
};
```

cond ? expr1 : expr 2 has value *expr1*, if *cond* holds, *expr2* otherwise

Felling Subtrees




```
struct tree_node {
  ...
  // POST: all nodes in the subtree with root
  // *this are deleted
  void clear() {
    if (left) {
      left->clear();
    }
    if (right) {
      right->clear();
    }
    delete this;
  }
};
```



Powerful Subtrees!

```
struct tree_node {
  ...
  // constructor
  tree_node (char o, tree_node* l,
             tree_node* r, double v)

  // functionality
  double eval () const;
  void print (std::ostream& o) const;
  int size () const;
  tree_node* copy () const;
  void clear ();
};
```

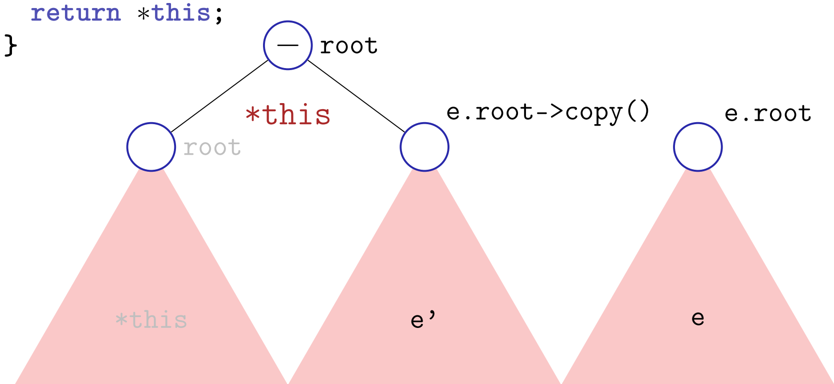

Planting Trees

```
class texpression {
private:
    tree_node* root;
public:
    ...
    texpression (double d)
       : root (new tree_node ('=', d, 0, 0)) {}
    ...
};
```

creates a tree with one leaf

Letting Trees Grow

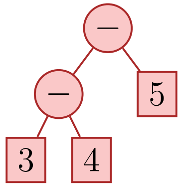
```
texpression& operator-= (const texpression& e)
{
  assert (e.root);
  root = new tree_node ('-', 0, root, e.root->copy());
  return *this;
}
```



Raising Trees

```
texpression operator- (const texpression& l,
                       const texpression& r)
{
    texpression result = l;
    return result -= r;
}

texpression a = 3;
texpression b = 4;
texpression c = 5;
texpression d = a-b-c;
```



Raising Trees

For `texpression` we also provide

- default constructor, copy constructor, assignment operator, destructor
- arithmetic assignments `+=, *=, /=`
- binary operators `+, *, /`
- the unary`-`

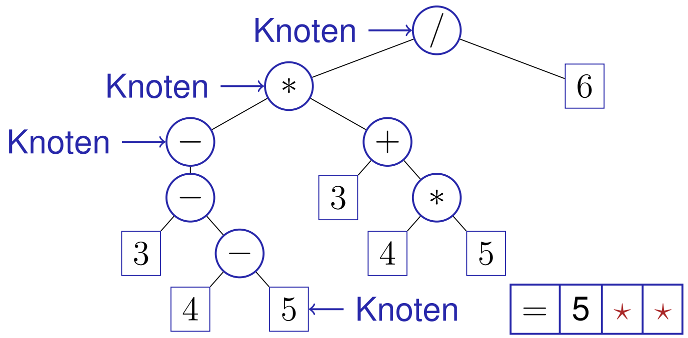
From Values to Trees!

```
typedef texpression result_type;   // Typ-Alias
```

```
// term = factor { "*" factor | "/" factor }
result_type term (std::istream& is){
{
  result_type value = factor (is);
  while (true) {
    if (consume (is, '*'))
      value *= factor (is);
    else if (consume (is, '/'))
      value /= factor (is);
    else
      return value;
  }
}
```

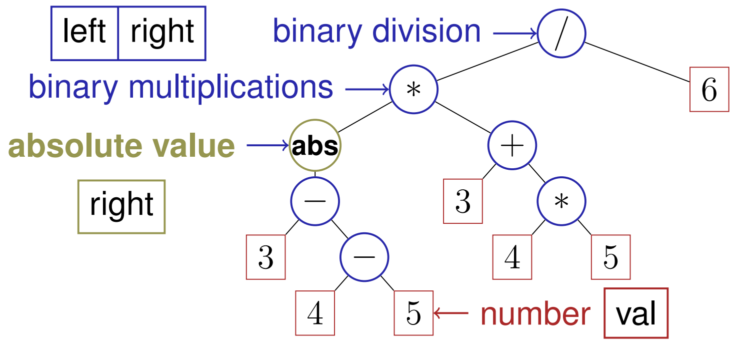
`double_calculator.cpp` (expression value) → `texpression_calculator_l.cpp` (expression tree)

Motivation Inheritance: Previously



- Nodes: Forks, Leafs and Bends
- ⇒ unused member variables ⋆

Motivation Inheritance: The Idea



- Everywhere only the necessary member variables
- Extension of “operator zoo” with new species!

Inheritance – The Hack, First...

Scenario: extension of the expression tree by mathematical functions **abs**, **sin**, **cos**:

- extension of the class **tree_node** by even more member variables

```
struct tree_node{
    char op; // neu: op = 'f' −> Funktion
    ...
    std::string name; // function name;
}
```

Disadvantages:

- Modification of the original code (undesirable)
- even more member variables...

Inheritance – The Hack, Second...

Scenario: extension of the expression tree by mathematical functions **abs**, **sin**, **cos**:

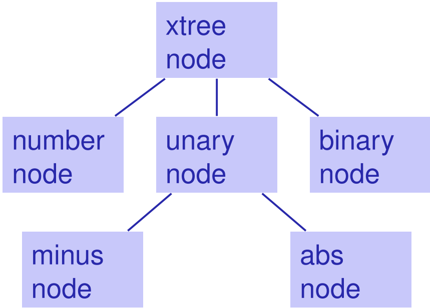
- Adaption of every single member function

```
double eval () const
{   ...
    else if (op == 'f')
        if (name == "abs")
            return std::abs(right−>eval());
    ...
}
```

Disadvantages:

- Loss of clarity
- hard to work in a team of developers

Inheritance – the Clean Solution



- "Split-up" of `tree_node`
- Common properties stay in the *base class* `xtree_node` (will be explained)

Inheritance

classes can *inherit* properties

```
struct xtree_node{
  virtual int size() const;
  virtual double eval () const;
};
```

erbt von (`:`) — inheritance visible (`public`)

```
struct number_node : public xtree_node {
  double val;                 ← only for number_node

  int size () const;          ← members of xtree_node
  double eval () const;       ← are overwritten
};
```

only for `number_node`

members of `xtree_node` are *overwritten*

Inheritance – Notation

```
class A {
    ...
}

class B: public A{
    ...
}

class C: public B{
    ...
}
```

`class A` — Base/Super Class

`class B: public A` — Subclass

"B and C *inherit* from A"
"C inherits from B"

Separation of Concerns: The Number Node

```
struct number_node: public xtree_node{
  double val;

  number_node (double v) : val (v) {}

  double eval () const {
    return val;
  }

  int size () const {
      return 1;
  }
};
```

A Number Node is a Tree Node...

- A (pointer to) an inheriting object can be used where (a pointer to) a base object is required , but not vice versa.

```
number_node* num = new number_node (5);

xtree_node* tn = num; // ok, number_node is
                      // just a special xtree_node

xtree_node* bn = new add_node (tn, num); // ok

number_node* nn = tn; //error:invalid conversion
```


Application

```
class xexpression {
private:
   xtree_node* root;
public:
    xexpression (double d)
      : root (new number_node (d)) {}

    xexpression& operator-= (const xexpression& t)
    {
      assert(t.root);
      root = new sub_node (root, t.root->copy());
      return *this;
    }
     ...
}
```

static type

dynamic type

Polymorphism

```
struct xtree_node {
  virtual double eval();
...
};
```

- Without **Virtual** the *static type* determines which function is executed

We do not go into further details.

Separation of Concerns: Binary Nodes

```
struct binary_node : public xtree_node {
  xtree_node* left; // INV != 0
  xtree_node* right; // INV != 0

  binary_node (xtree_node* l, xtree_node* r) :
    left (l), right (r)
  {
    assert (left);
    assert (right);
  }

  int size () const {
    return 1 + left->size() + right->size();
  }
};
```

size works for *all* binary nodes. Derived classes (add_node,sub_node...) *inherit* this function!

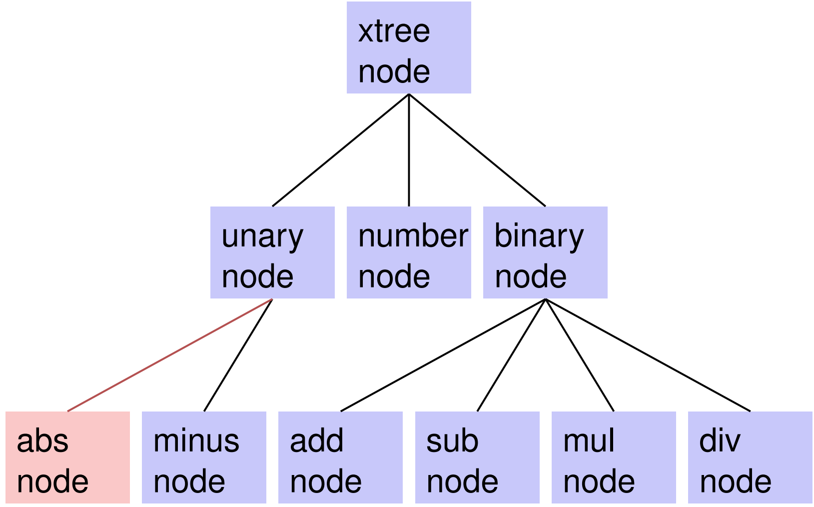
Separation of Concerns: +, −, ∗ ...

```
struct sub_node : public binary_node {
  sub_node (xtree_node* l, xtree_node* r)
    : binary_node (l, r) {}

  double eval () const {
    return left->eval() - right->eval();
  }
};
```

eval specific
for +, −, ∗, /

Extension by abs Function



Extension by abs Function

```
struct unary_node: public xtree_node
{
  xtree_node* right; // INV != 0
  unary_node (xtree_node* r);
  int size () const;
};

struct abs_node: public unary_node
{
  abs_node (xtree_node* arg) : unary_node (arg) {}

  double eval () const {
    return std::abs (right->eval());
  }

};
```


Do not forget... Memory Management

```
struct xtree_node {
  ...
  // POST: a copy of the subtree with root
  //       *this is made, and a pointer to
  //       its root node is returned
  virtual xtree_node* copy () const;

  // POST: all nodes in the subtree with
  //        root *this are deleted
  virtual void clear () {};
};
```

Do not forget… Memory Management

```
struct unary_node: public xtree_node {
  ...
  virtual void clear () {
    right->clear();
    delete this;
  }
};

struct minus_node: public unary_node {
  ...
  xtree_node* copy () const
  {
    return new minus_node (right->copy());
  }
};
```


xtree_node is no dynamic data type ??

- We do not have any variables of type `xtree_node` with automatic memory lifetime
- copy constructor, assignment operator and destructor are unnecessary
- memory management in the *container class*

```
class xexpression {
  // Copy-Konstruktor
  xexpression (const xexpression& v);
  // Zuweisungsoperator
  xexpression& operator=(const xexpression& v);
  // Destruktor
  ~xexpression ();
};
```

xtree_node::copy

xtree_node::clear

Mission: Monolithic → Modular ✓

```
struct tree_node {
  char op;
  double val;
  tree_node* left;
  tree_node* right;
  ...

  double eval () const
  {
    if (op == '=') return val;
    else {
    double l = 0;
    if (left != 0) l = left->eval();
    double r = right->eval();
    if (op == '+') return l + r;
    if (op == '-') return l - r;
    if (op == '*') return l * r;
    if (op == '/') return l / r;
    assert (false); // unknown operator
    return 0;
  }

  int size () const { ... }

  void clear() { ... }

  tree_node* copy () const { ... }

};
```

```
struct number_node: public xtree_node {
  double val;
  ...
  double eval () const {
  return val;
  }
};

struct minus_node: public unary_node {
  ...
  double eval () const {
    return -right->eval();
  }
};

struct minus_node : public binary_node {
  ...
  double eval () const {
    return left->eval() - right->eval();
  }
}
```

+

```
struct abs_node : public unary_node {
  ...
  double eval () const {
    return left->eval() - right->eval();
  }
}
```


Summary of the Concepts

.. of Object Oriented Programming

Encapsulation

- hide the implementation details of types
- definition of an interface for access to values and functionality (public area)
- make possible to ensure invariants and the modification of the implementation

Summary of Concepts

.. of Object Oriented Programming

Inheritance

- types can inherit properties of types
- inheriting types can provide new properties and overwrite existing ones
- allows to reuse code and data

Summary of Concepts

.. of Object Oriented Programming

Polymorphism

- A pointer may, depending on its use, have different underlying types
- the different underlying types can react differently on the same access to their common interface
- makes it possible to extend libraries “non invasively”