Object-Oriented Patterns & Frameworks

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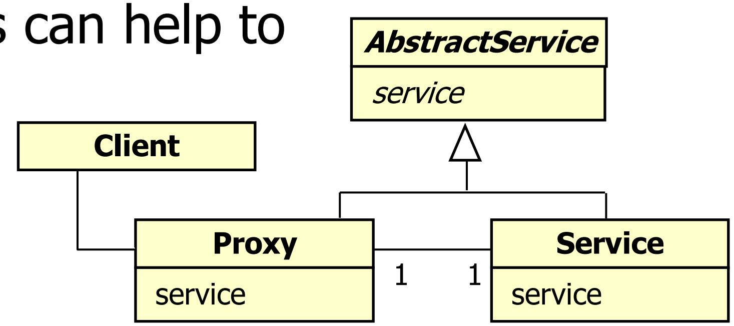
Goals of this Presentation

Show *by example* how patterns & frameworks can help to

- *Codify good OO software design & implementation practices*
  - distill & generalize experience
  - aid to novices & experts alike
- *Give design structures explicit names*
  - common vocabulary
  - reduced complexity
  - greater expressivity
- *Capture & preserve design & implementation knowledge*
  - articulate key decisions succinctly
  - improve documentation
- *Facilitate restructuring/refactoring*
  - patterns & frameworks are interrelated
  - enhance flexibility, reuse, & productivity




```
class Reactor {
public:
  /// Singleton access point.
  static Reactor *instance (void);

  /// Run event loop.
  void run_event_loop (void);

  /// End event loop.
  void end_event_loop (void);

  /// Register @a event_handler
  /// for input events.
  void register_input_handler
    (Event_Handler *eh);

  /// Remove @a event_handler
  /// for input events.
  void remove_input_handler
    (Event_Handler *eh);
```

Tutorial Overview

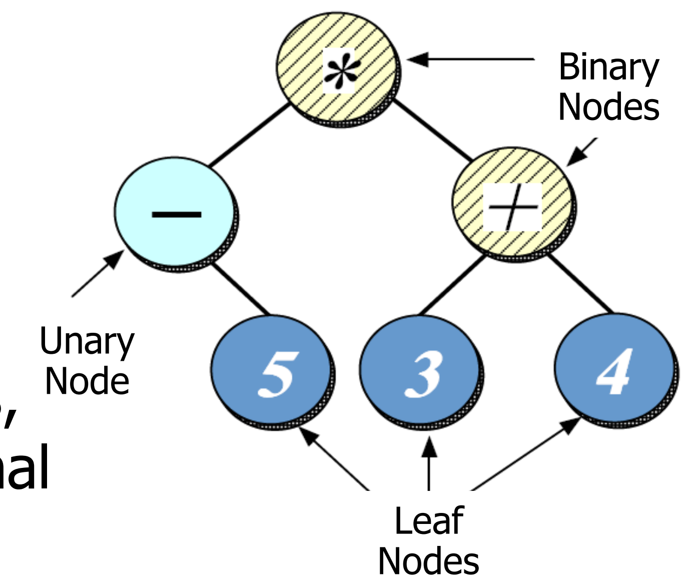
Part I: Motivation & Concepts

- The issue
- What patterns & frameworks are
- What they're good for
- How we develop & categorize them

		Purpose		
		Creational	**Structural**	**Behavioral**
Scope	**Class**	Factory Method	Adapter (class)	Interpreter Template Method
	Object	Abstract Factory Builder Prototype Singleton	Adapter (object) Bridge Composite Decorator Flyweight Facade Proxy	Chain of Responsibility Command Iterator Mediator Memento Observer State Strategy Visitor

Part II: Case Study

- Use patterns & frameworks to build an expression tree application
- Demonstrate usage & benefits

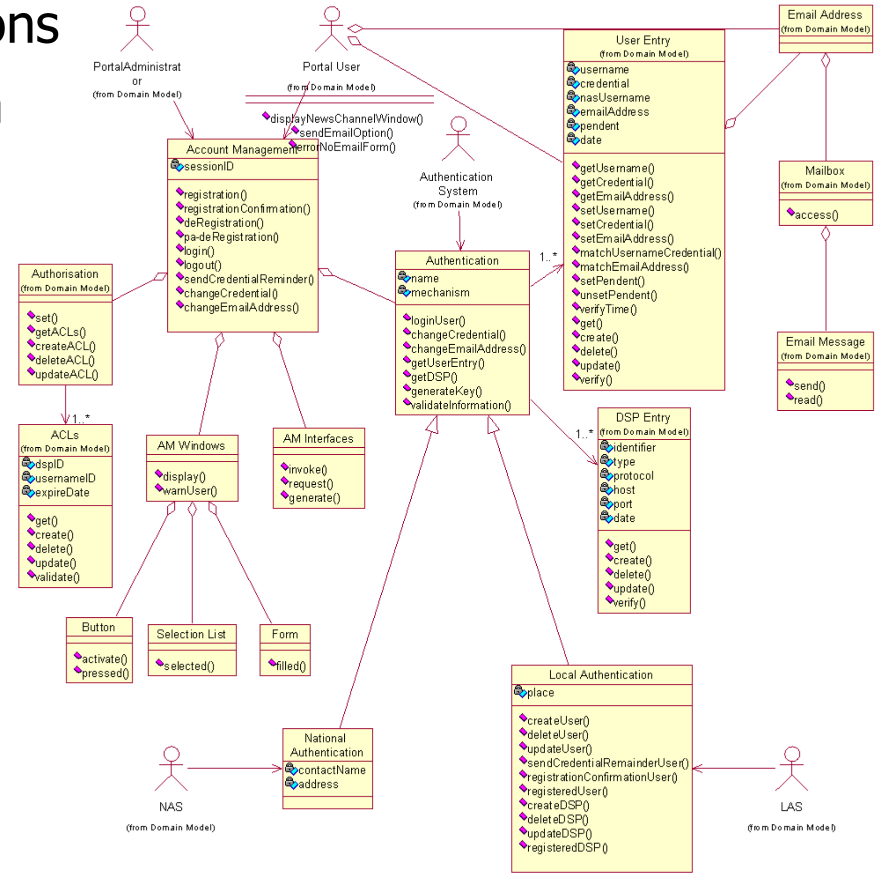


Part III: Wrap-Up

- Life beyond the GoF book, observations, caveats, concluding remarks, & additional references

Part I: Motivation & Concepts

- OOD methods emphasize design notations
  - Fine for specification & documentation

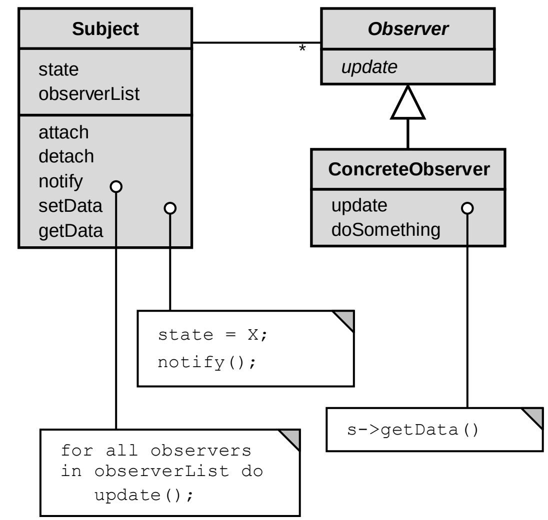


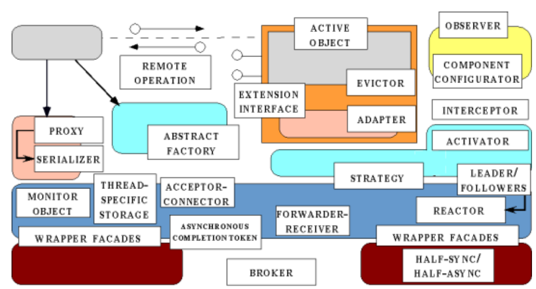
Part I: Motivation & Concepts

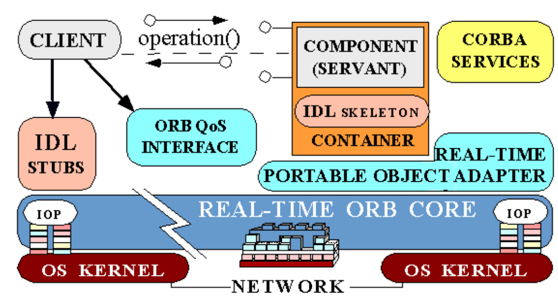
- OOD methods emphasize design notations
  - Fine for specification & documentation
- But OOD is more than just drawing diagrams
  - Good draftsmen are not necessarily good architects!

Part I: Motivation & Concepts

- OOD methods emphasize design notations
  - Fine for specification & documentation
- But OOD is more than just drawing diagrams
  - Good draftsmen are not necessarily good architects!
- Good OO designers rely on lots of experience
  - At least as important as syntax
- Most powerful reuse combines *design & code* reuse
  - *Patterns*: Match problem to design experience
  - *Frameworks*: Reify patterns within a domain context



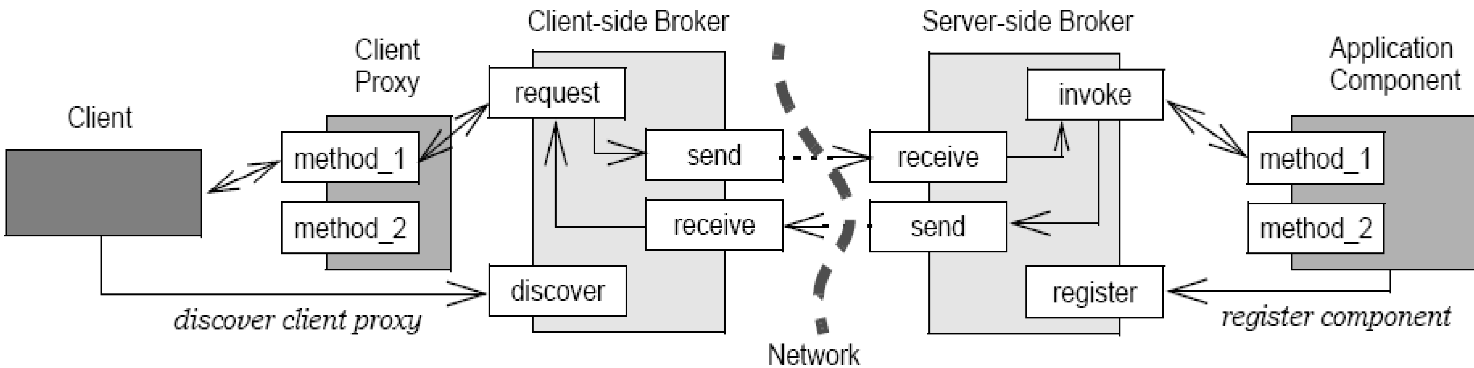




Recurring Design Structures

Well-designed OO systems exhibit recurring structures that promote

- Abstraction
- Flexibility
- Modularity
- Elegance

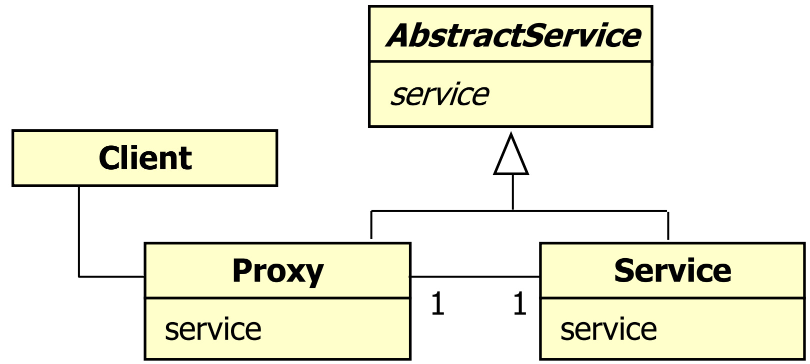


Therein lies valuable design knowledge

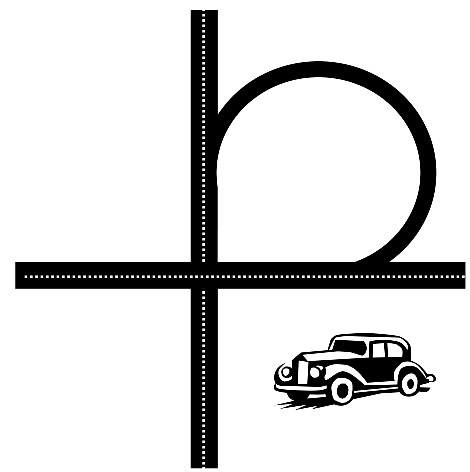
Problem: capturing, communicating, applying, & preserving this knowledge without undue time, effort, & risk

A *Pattern*…

- Abstracts & names a recurring design structure
- Comprises class and/or object
  - Dependencies
  - Structures
  - Interactions
  - Conventions
- Specifies the design structure explicitly
- Is distilled from actual design experience



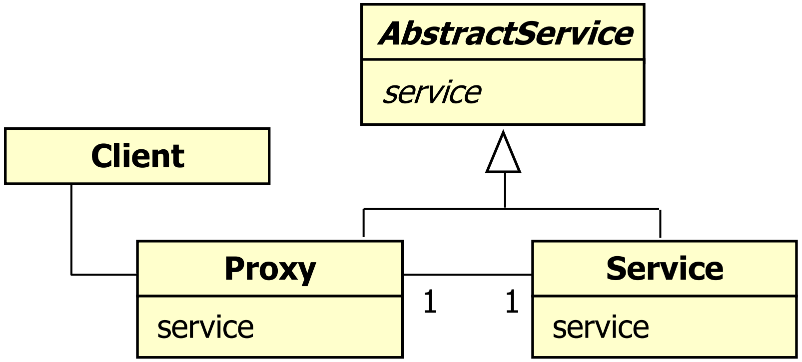
The Proxy Pattern



Presents solution(s) to common (software) problem(s) arising within a context

Four Basic Parts of a Pattern

1. Name
2. Problem (including "forces" & "applicability")
3. Solution (both visual & textual descriptions)
4. Consequences & trade-offs of applying the pattern

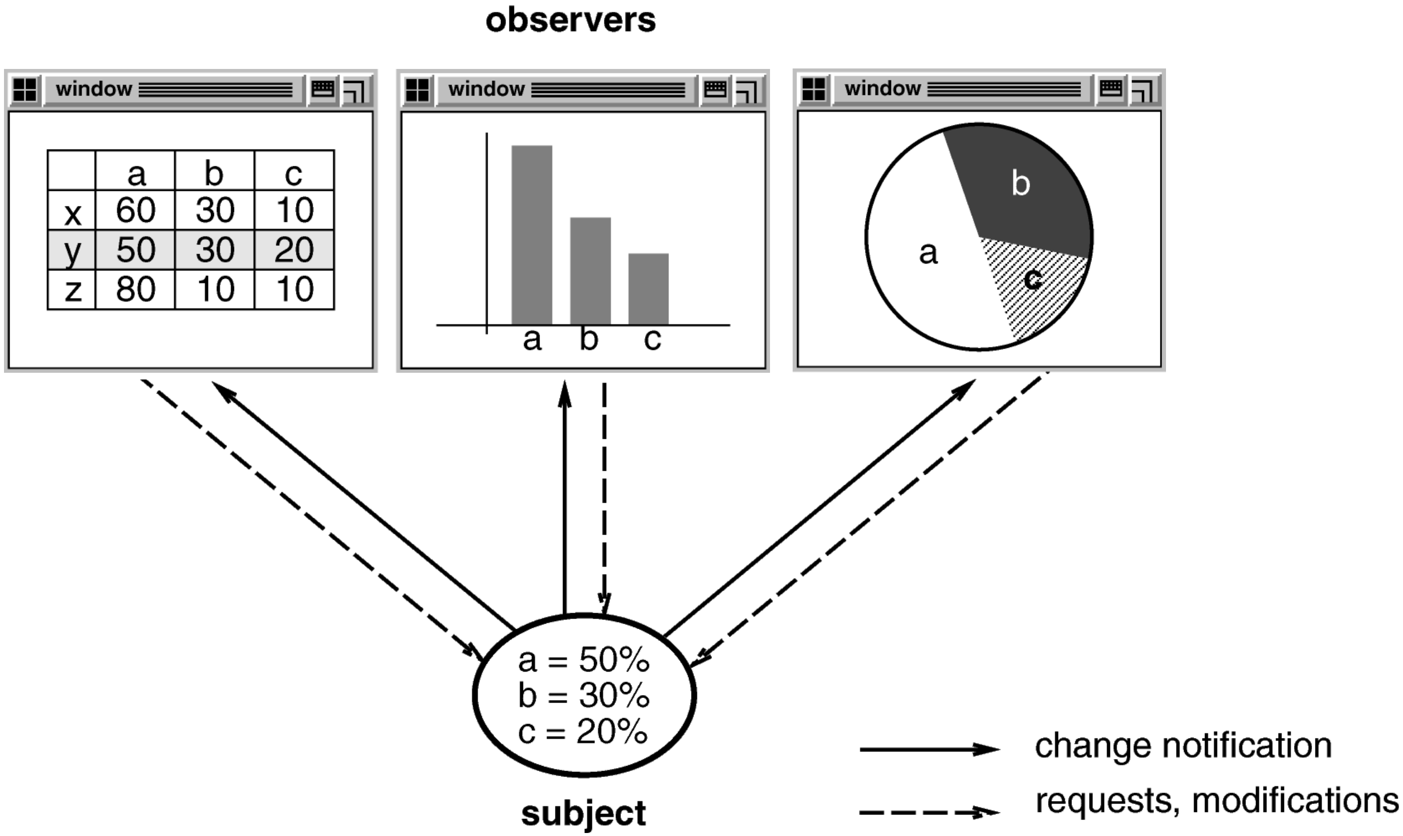


The Proxy Pattern

Key characteristics of patterns include:

- Language- & implementation-independent
- "Micro-architecture," i.e., "society of objects"
- Adjunct to existing methodologies (RUP, Fusion, SCRUM, etc.)

Example: Observer



Observer object behavioral

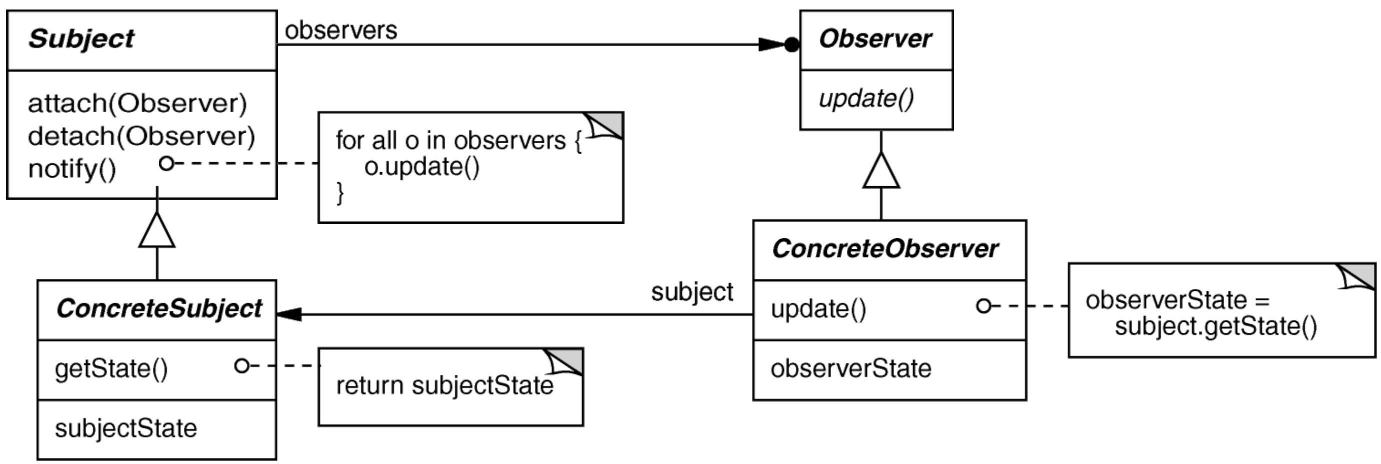
Intent

define a one-to-many dependency between objects so that when one object changes state, all dependents are notified & updated

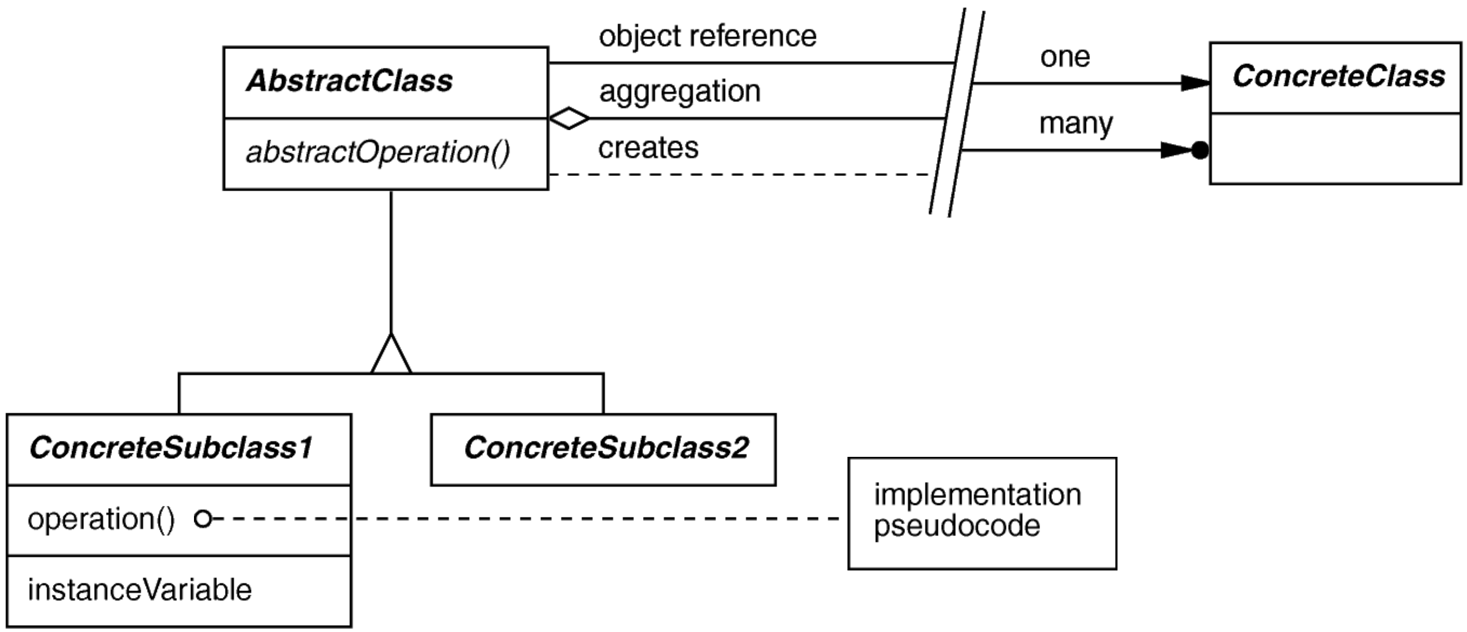
Applicability

– an abstraction has two aspects, one dependent on the other
– a change to one object requires changing untold others
– an object should notify unknown other objects

Structure



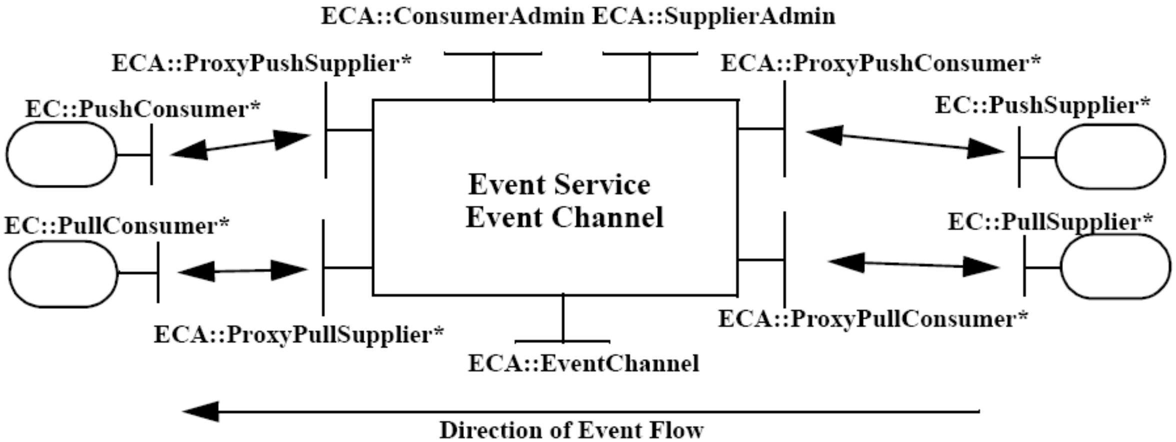
Modified UML/OMT Notation



Observer object behavioral

```
class ProxyPushConsumer : public // …
  virtual void push (const CORBA::Any &event) {
    for (std::vector<PushConsumer>::iterator i
          (consumers.begin ()); i != consumers.end (); i++)
      (*i).push (event);
  }

class MyPushConsumer : public // ….
  virtual void push
   (const CORBA::Any &event) { /* consume the event. */ }
```



CORBA Notification Service example using C++ Standard Template Library (STL) iterators (which is an example of the Iterator pattern from GoF)

Observer object behavioral

Consequences

+ modularity: subject & observers may vary independently
+ extensibility: can define & add any number of observers
+ customizability: different observers offer different views of subject
– unexpected updates: observers don't know about each other
– update overhead: might need hints or filtering

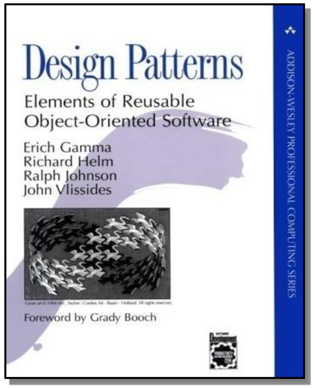
Implementation

– subject-observer mapping
– dangling references
– update protocols: the push & pull models
– registering modifications of interest explicitly

Known Uses

– Smalltalk Model-View-Controller (MVC)
– InterViews (Subjects & Views, Observer/Observable)
– Andrew (Data Objects & Views)
– Smart phone event frameworks (e.g., Symbian, Android, iPhone)
– Pub/sub middleware (e.g., CORBA Notification Service, Java Message Service, DDS)
– Mailing lists

Design Space for GoF Patterns



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Scope: domain over which a pattern applies

Purpose: reflects what a pattern does

GoF Pattern Template (1st half)

Intent

short description of the pattern & its purpose

Also Known As

Any aliases this pattern is known by

Motivation

motivating scenario demonstrating pattern's use

Applicability

circumstances in which pattern applies

Structure

graphical representation of pattern using modified UML notation

Participants

participating classes and/or objects & their responsibilities

GoF Pattern Template (2nd half)

...

Collaborations

how participants cooperate to carry out their responsibilities

Consequences

the results of application, benefits, liabilities

Implementation

pitfalls, hints, techniques, plus language-dependent issues

Sample Code

sample implementations in C++, Java, C#, Python, Smalltalk, C, etc.

Known Uses

examples drawn from existing systems

Related Patterns

discussion of other patterns that relate to this one

Benefits & Limitations of Patterns

Benefits

- *Design* reuse
- Uniform design vocabulary
- Enhance understanding, restructuring, & team communication
- Basis for automation
- Transcends language-centric biases/myopia
- Abstracts away from many unimportant details

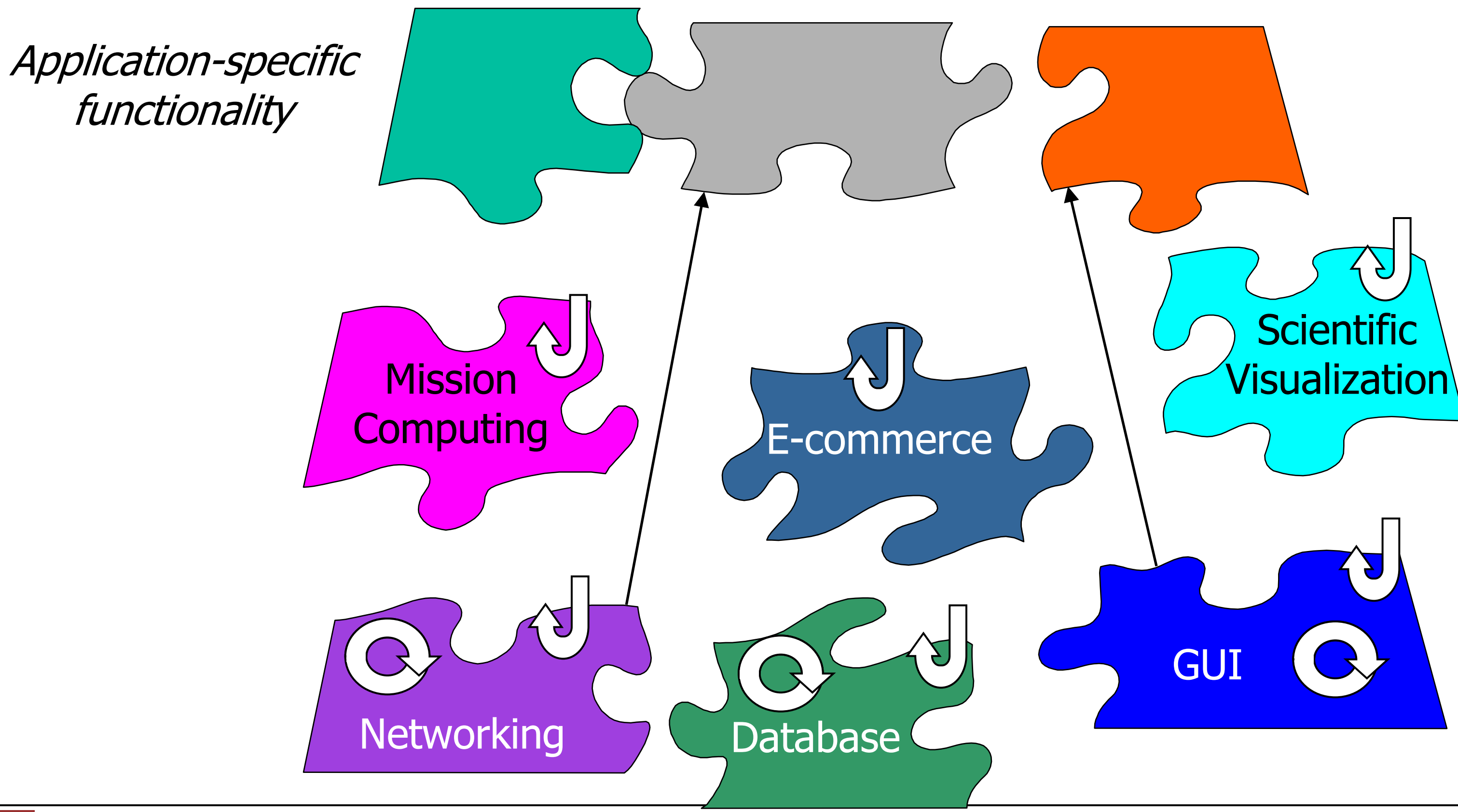
Limitations

- Require significant tedious & error-prone human effort to handcraft pattern implementations *design* reuse
- Can be deceptively simple uniform design vocabulary
- May limit design options
- Leaves important (implementation) details unresolved

Addressing the limitations of patterns requires more than just *design* reuse

Overview of Frameworks

- Frameworks exhibit "inversion of control" at runtime via callbacks
- Frameworks provide integrated domain-specific structures & functionality
- Frameworks are "semi-complete" applications



Motivation for Frameworks







Proprietary & Stovepiped Application & Infrastructure Software




Standard/COTS Hardware & Networks

Legacy embedded systems have historically been:

- Stovepiped
- Proprietary
- Brittle & non-adaptive
- Expensive
- Vulnerable

Consequence: Small HW/SW changes have big (negative) impact on system QoS & maintenance

Motivation for Frameworks

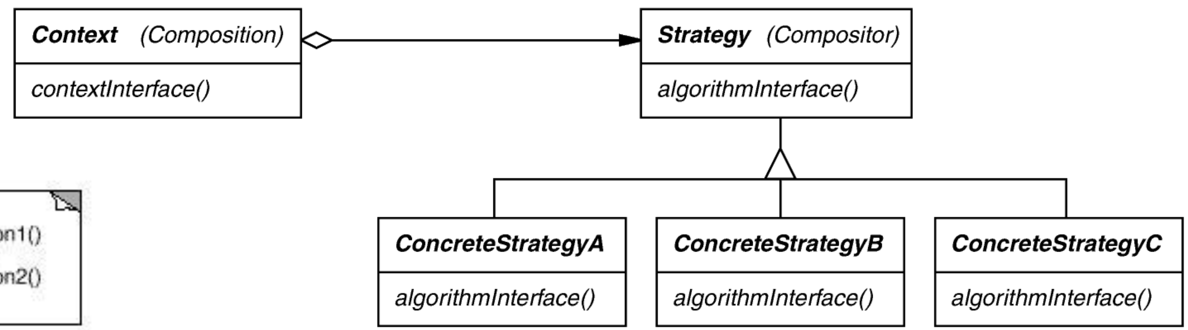
Product-Line Architecture-based Application & Framework Software

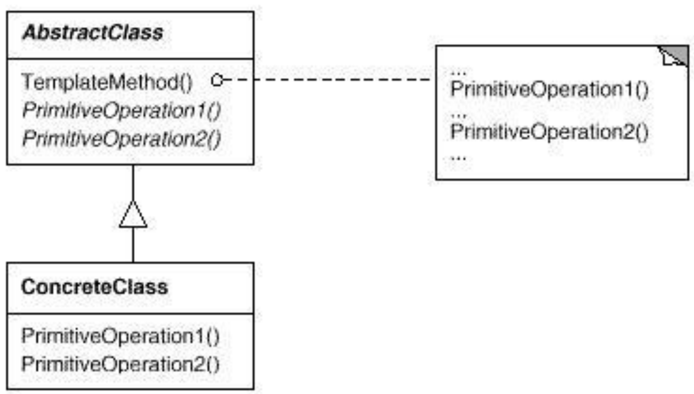
Standard/COTS Hardware & Networks

- ***Frameworks*** factors out many reusable general-purpose & domain-specific services from traditional DRE application responsibility
- Essential for ***product-line architectures (PLAs)***
- Product-lines & frameworks offer many configuration opportunities
  - e.g., component distribution/deployment, OS, protocols, algorithms, etc.

Categories of OO Frameworks

- *White-box frameworks* are reused by subclassing, which usually requires understanding the implementation of the framework to some degree
- *Black-box framework* is reused by parameterizing & assembling framework objects, thereby hiding their implementation from users
- Each category of OO framework uses different sets of patterns, e.g.:





– *Black-box frameworks* reply heavily on object composition patterns, such as Strategy & Decorator

– *White-box frameworks* rely heavily on inheritance-based patterns, such as Template Method & State

Many frameworks fall in between white-box & black-box categories

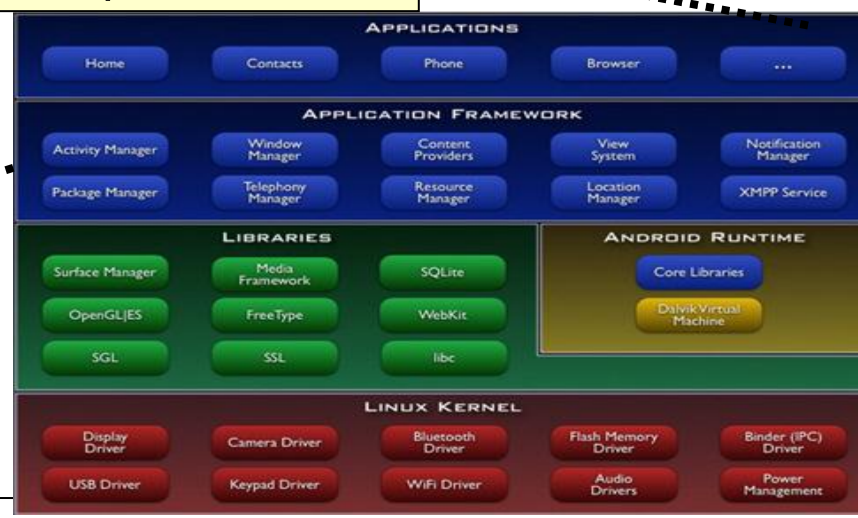
Commonality & Variability Analysis in Frameworks

- Framework characteristics are captured via *Scope, Commonalities, & Variabilities (SCV) analysis*
  - This process can be applied to identify commonalities & variabilities in a domain to guide development of a framework

- Applying SCV to Android smartphones
  - Scope defines the domain & context of the framework
    - Component architecture, object-oriented application frameworks, & associated components, e.g., GPS, Network, & Display

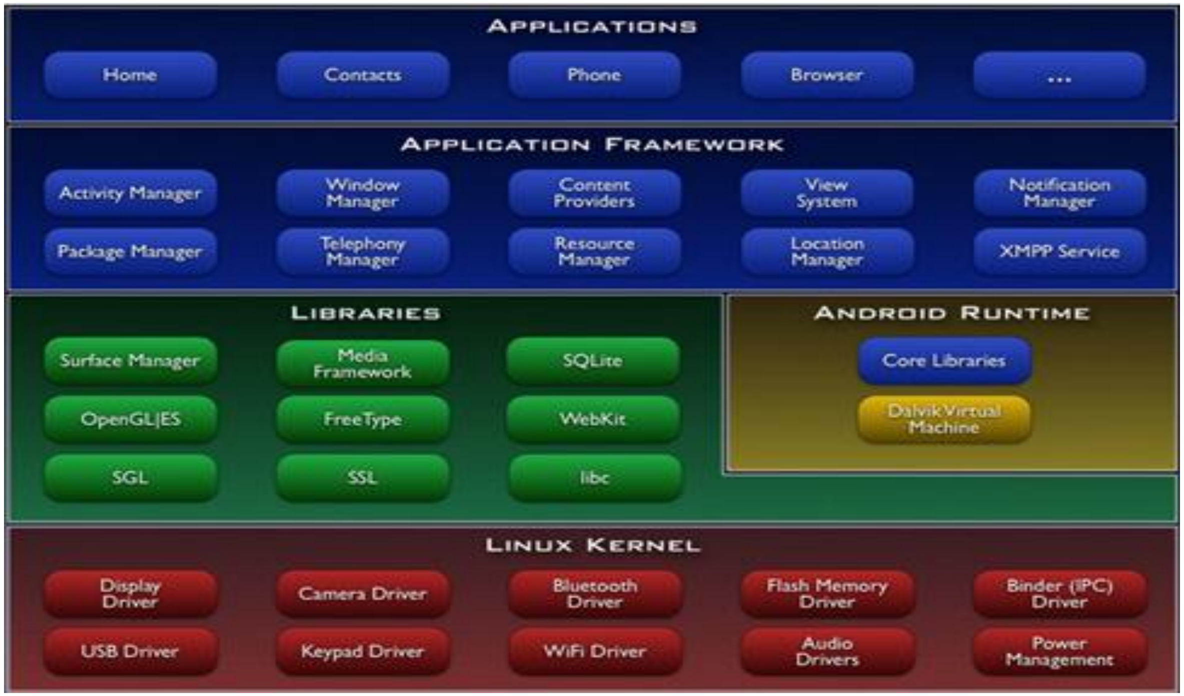
Reusable Application Components

Reusable Architecture Framework



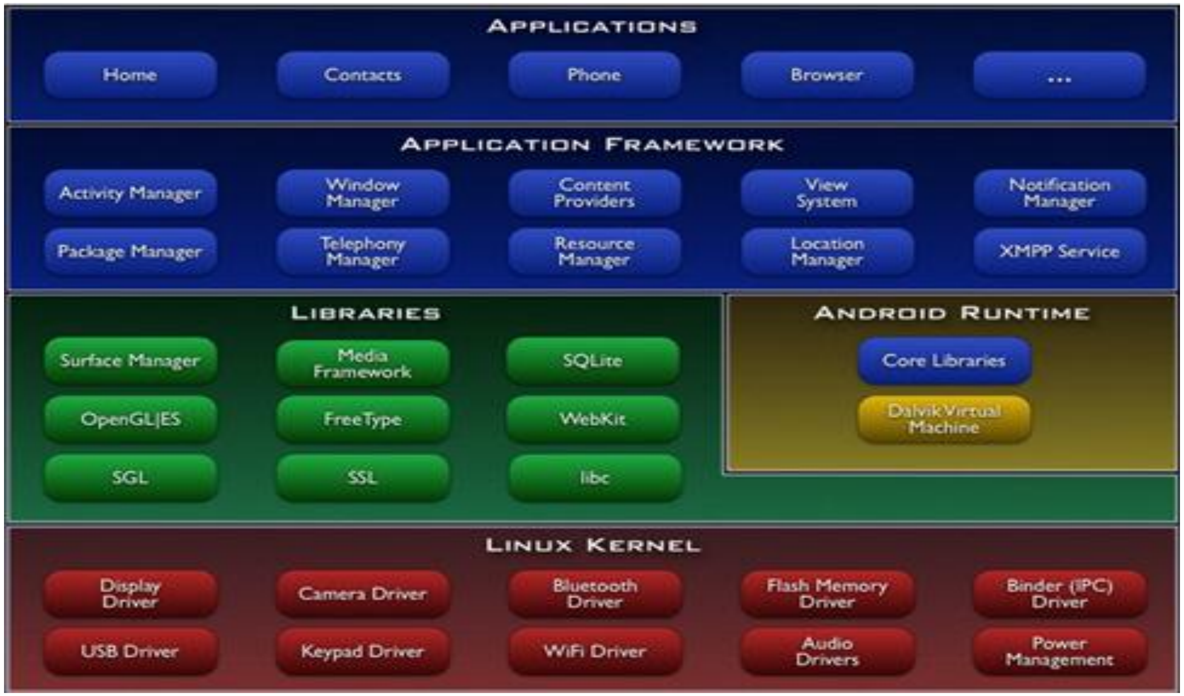
Applying SCV to an Android Framework

- ***Commonalities*** describe the attributes that are common across all members of the framework
  - Common object-oriented frameworks & set of component types
    - e.g., Activities, Services, Content Providers, & Display components
  - Common middleware infrastructure
    - e.g., Intents framework, Binder, etc.

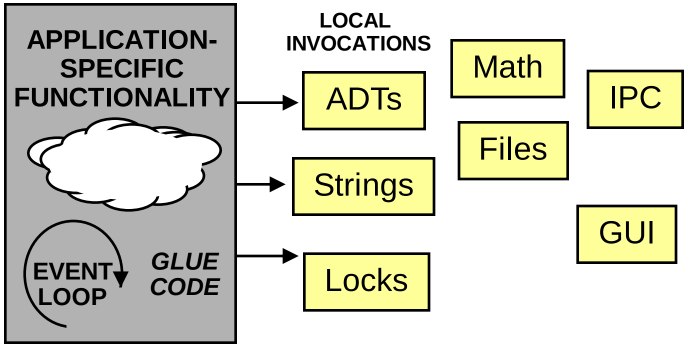


Applying SCV to an Android Framework

- ***Variabilities*** describe the attributes unique to the different members of the framework
  - Product-dependent component implementations, e.g., Motorola, HTC, Samsug
  - Product-dependent component connections
  - Product-dependent component assemblies (e.g., CDMA vs. GSM in different countries)
  - Different hardware, OS, & network/bus configurations

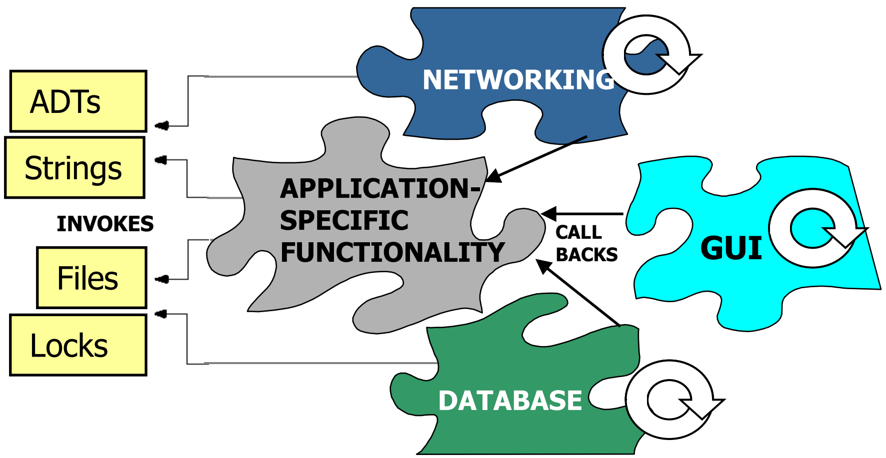


Comparing Reuse Techniques



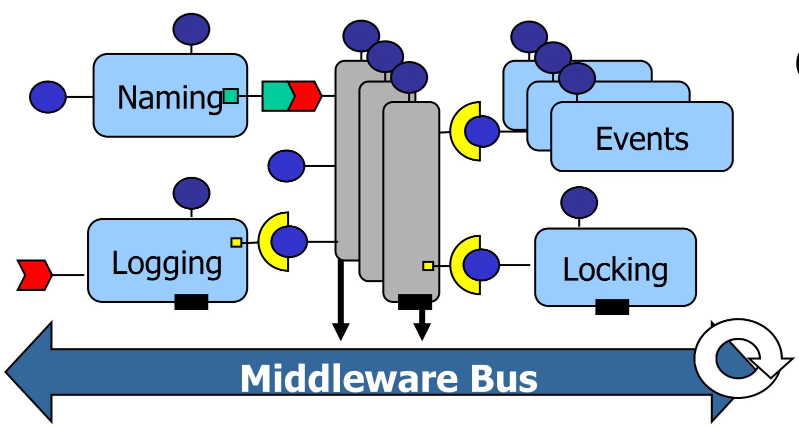
Class Library (& STL) Architecture

- A ***class*** is an implementation unit in an OO programming language, i.e., a reusable ***type*** that often implements ***patterns***
- Classes in class libraries are typically *passive*



Framework Architecture

- A ***framework*** is an integrated set of classes that collaborate to form a reusable architecture for a family of applications
- Frameworks implement ***pattern languages***



Component & Service-Oriented Architecture

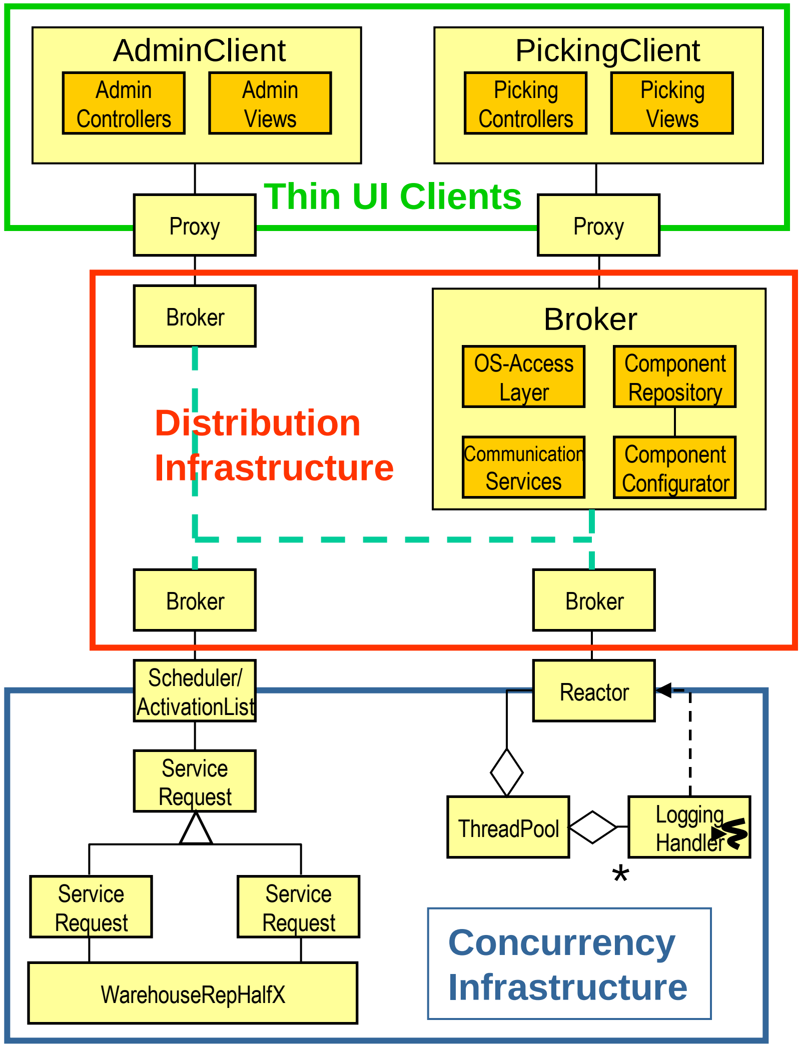
- A ***component*** is an encapsulation unit with one or more interfaces that provide clients with access to its services
- Components can be deployed & configured via ***assemblies***

Taxonomy of Reuse Techniques

Class Libraries	Frameworks	Components
Micro-level	Meso-level	Macro-level
Stand-alone language entities	"Semi-complete" applications	Stand-alone composition entities
Domain-independent	Domain-specific	Domain-specific or Domain-independent
Borrow caller's thread	Inversion of control	Borrow caller's thread

Benefits of Frameworks

- **Design reuse**
  - e.g., by guiding application developers through the steps necessary to ensure successful creation & deployment of software



Benefits of Frameworks

- **Design reuse**
  - e.g., by guiding application developers through the steps necessary to ensure successful creation & deployment of software
- **Implementation reuse**
  - e.g., by amortizing software lifecycle costs & leveraging previous development & optimization efforts

```
package org.apache.tomcat.session;

import org.apache.tomcat.core.*;
import org.apache.tomcat.util.StringManager;
import java.io.*;
import java.net.*;
import java.util.*;
import javax.servlet.*;
import javax.servlet.http.*;

/**
 * Core implementation of a server session
 *
 * @author James Duncan Davidson [duncan@eng.sun.com]
 * @author James Todd [gonzo@eng.sun.com]
 */

public class ServerSession {

    private StringManager sm =
        StringManager.getManager("org.apache.tomcat.session");
    private Hashtable values = new Hashtable();
    private Hashtable appSessions = new Hashtable();
    private String id;
    private long creationTime = System.currentTimeMillis();;
    private long thisAccessTime = creationTime;
private int inactiveInterval = -1;

    ServerSession(String id) {
        this.id = id;
    }

    public String getId() {
        return id;
    }

    public long getCreationTime() {
        return creationTime;
    }

    public ApplicationSession getApplicationSession(Context context,
        boolean create) {
        ApplicationSession appSession =
            (ApplicationSession)appSessions.get(context);

        if (appSession == null && create) {

            // XXX
            // sync to ensure valid?

            appSession = new ApplicationSession(id, this, context);
            appSessions.put(context, appSession);
        }

        // XXX
        // make sure that we haven't gone over the end of our
        // inactive interval -- if so, invalidate & create
        // a new appSession

        return appSession;
    }

    void removeApplicationSession(Context context) {
        appSessions.remove(context);
    }
```

Benefits of Frameworks

- **Design reuse**
  - e.g., by guiding application developers through the steps necessary to ensure successful creation & deployment of software
- **Implementation reuse**
  - e.g., by amortizing software lifecycle costs & leveraging previous development & optimization efforts
- **Validation reuse**
  - e.g., by amortizing the efforts of validating application- & platform-independent portions of software, thereby enhancing software reliability & scalability

Build Scoreboard

Doxygen

Build Name	Last Finished	Config	Setup	Compile	Tests	Status
Doxygen	Sep 05, 2002 - 03:24	[Config]	[Full]	[Full] [Brief]		Inactive

Linux

Build Name	Last Finished	Config	Setup	Compile	Tests	Status
Debian_Core	Sep 05, 2002 - 14:36	[Config]	[Full]	[Full]		Inactive
Debian_Full	Sep 05, 2002 - 12:19	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive
Debian_Full_Reactors	Sep 05, 2002 - 11:59	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive
Debian_GCC_3.0.4	Sep 05, 2002 - 13:45	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Compile
Debian_Minimum	Sep 05, 2002 - 08:51	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Compile
Debian_Minimum_Static	Sep 04, 2002 - 00:53	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Setup
Debian_NoInline	Sep 05, 2002 - 12:31	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Compile
Debian_NoInterceptors	Sep 05, 2002 - 09:10	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive
Debian_WChar_GCC_3.1	Sep 05, 2002 - 01:23	[Config]	[Full]	[Full]	[Full] [Brief]	Compile
RedHat_7.1_Full	Sep 04, 2002 - 02:34	[Config]	[Full]	[Full]	[Full] [Brief]	Setup
RedHat_7.1_No_AMI_Messaging	Sep 05, 2002 - 04:56	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Compile
RedHat_Core	Sep 05, 2002 - 14:34	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Compile
RedHat_Explicit_Templates	Sep 05, 2002 - 08:56	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive
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RedHat_Implicit_Templates	Sep 03, 2002 - 06:25	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive
RedHat_Single_Threaded	Sep 05, 2002 - 10:55	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Compile
RedHat_Static	Sep 05, 2002 - 15:24	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive

Lynx

Build Name	Last Finished	Config	Setup	Compile	Tests	Status
Lynx_PPC	Sep 03, 2002 - 10:58	[Config]	[Full]	[Full] [Brief]		Setup

Limitations of Frameworks

- Frameworks are powerful, but can be hard to use effectively (& even harder to create) for many application developers
  - Commonality & variability analysis requires significant domain knowledge & OO design/implementation expertise
- Significant time required to evaluate applicability & quality of a framework for a particular domain
- Debugging is tricky due to inversion of control
- V&V is tricky due to "late binding"
- May incur performance degradations due to extra (unnecessary) levels of indirection

www.cs.wustl.edu/ ~schmidt/PDF/Queue-04.pdf

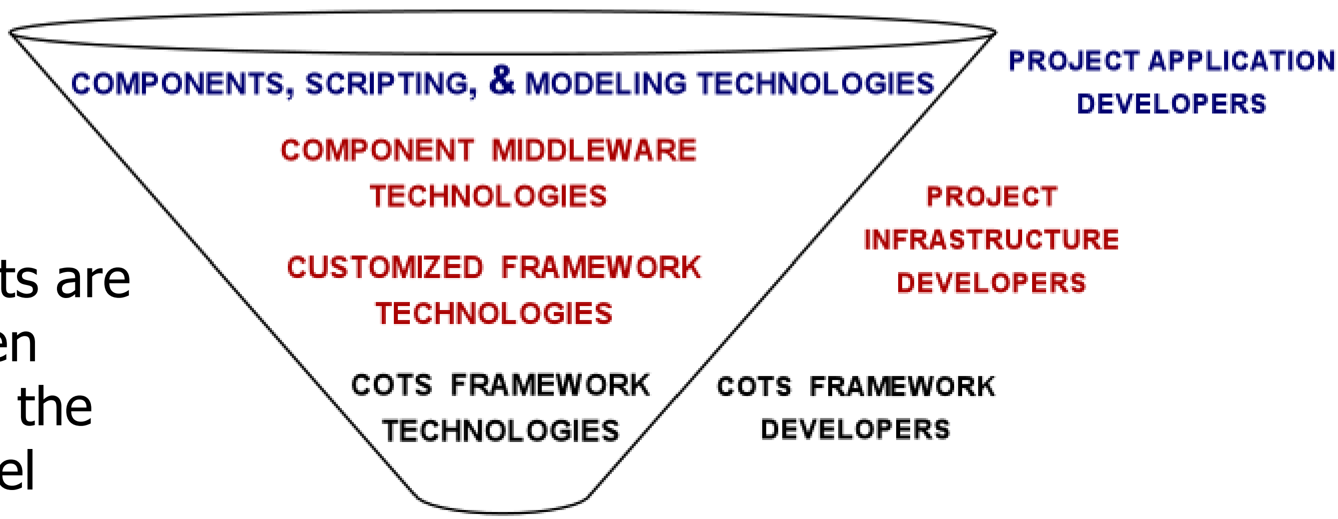
Many frameworks limitations can be addressed with knowledge of patterns!

Using Frameworks Effectively

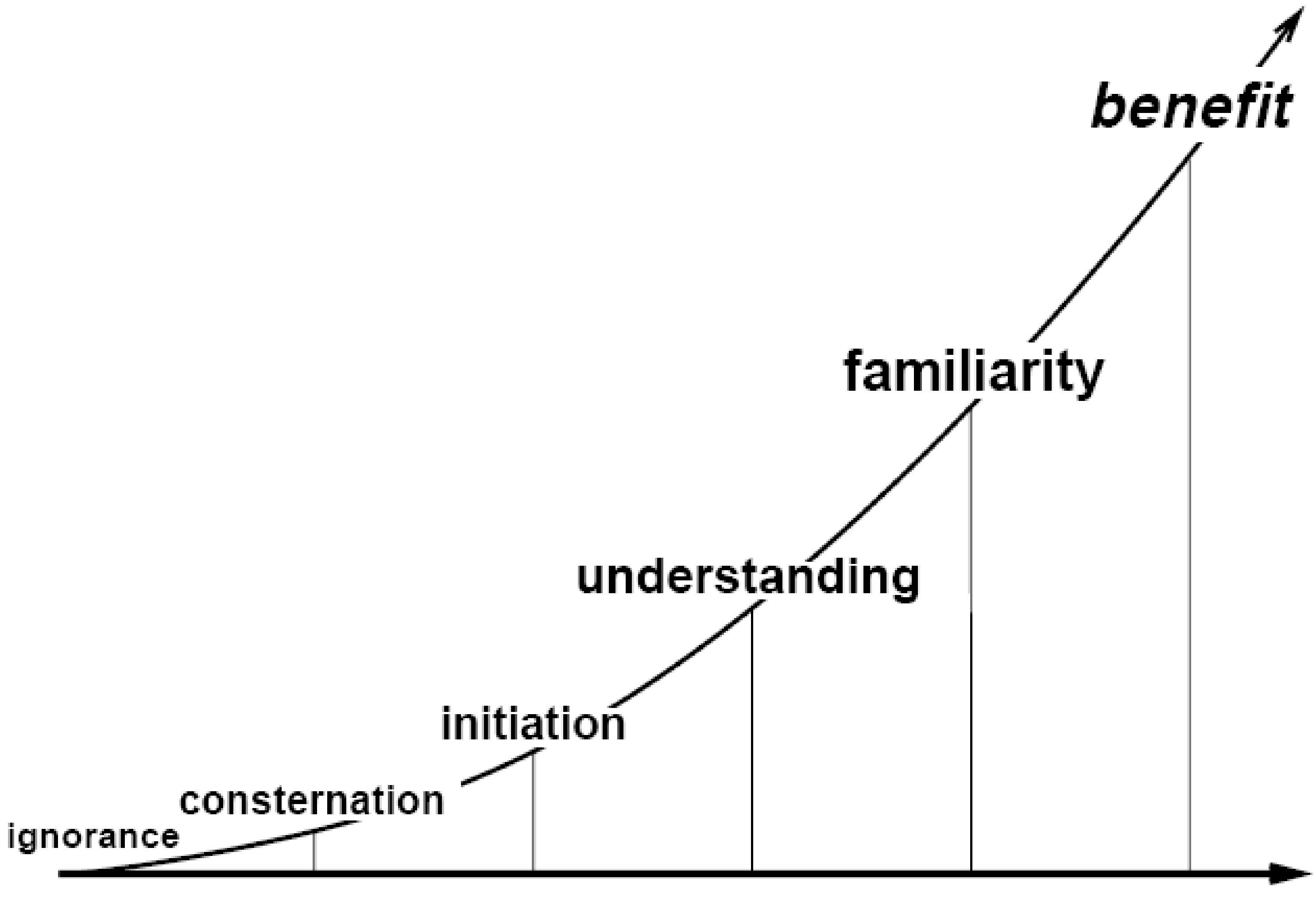
Observations

- Since frameworks are powerful—but but hard to develop & use effectively by application developers—it's often better to use & customize COTS frameworks than to develop in-house frameworks
- Classes/components/services are easier for application developers to use, but aren't as powerful or flexible as frameworks

Successful projects are therefore often organized using the "funnel" model



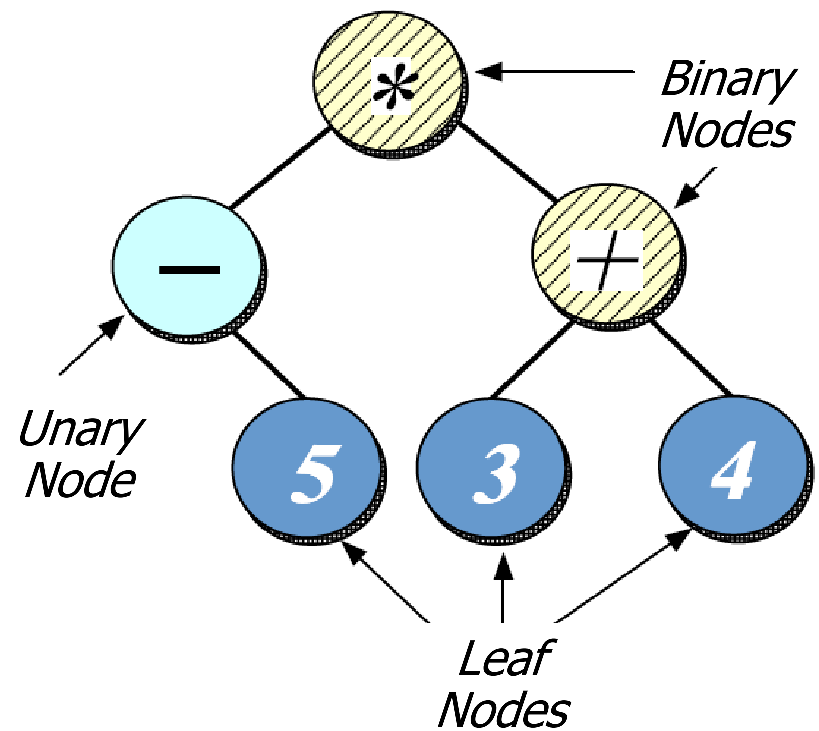
Stages of Pattern & Framework Awareness



Part II: Case Study: Expression Tree Application

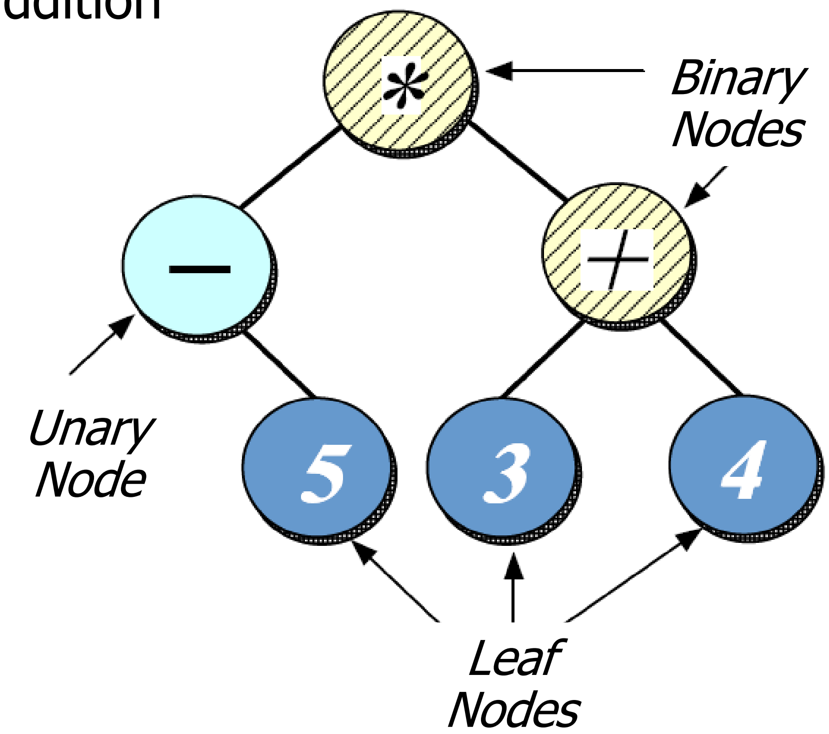
Goals

- Develop an object-oriented expression tree evaluator program using *patterns* & *frameworks*
- Demonstrate commonality/variability analysis in the context of a concrete application example
- Illustrate how OO frameworks can be combined with the generic programming features of C++ & STL
- Compare/contrast OO & non-OO approaches



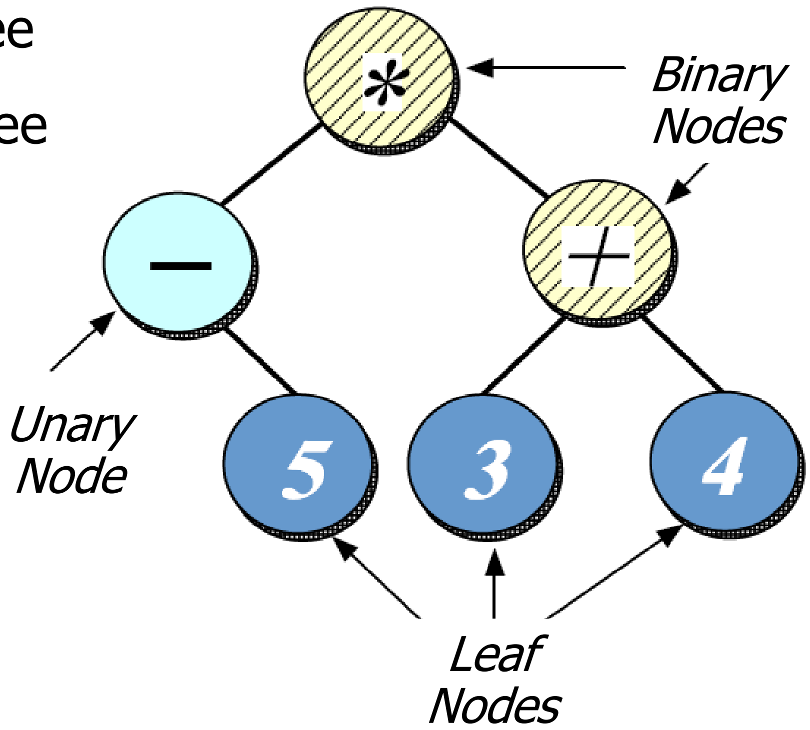
Overview of Expression Tree Application

- Expression trees consist of nodes containing *operators* & *operands*
- Operators have different precedence levels, different associativities, & different arities, e.g.:
  - Multiplication takes precedence over addition
  - The multiplication operator has two arguments, whereas unary minus operator has only one
- Operands can be integers, doubles, variables, etc.
  - We'll just handle integers in this application
  - Application can be extended easily



Overview of Expression Tree Application

- Trees may be "evaluated" via different traversal orders
  - e.g., in-order, post-order, pre-order, level-order
- The evaluation step may perform various operations, e.g.:
  - Print the contents of the expression tree
  - Return the "value" of the expression tree
  - Generate code
  - Perform semantic analysis & optimization
  - *etc.*



See www.dre.vanderbilt.edu/~schmidt/qualcomm-india/tree-traversal.zip

Using the Expression Tree Application

- By default, the expression tree application can run in "succinct mode," e.g.:

```
% tree-traversal
> 1+4*3/2
7
> (8/4) * 3 + 1
7
^D
```

- You can also run the expression tree application in "verbose mode," e.g.:

```
% tree-traversal -v
format [in-order]
expr [expression]
print [in-order|pre-order|post-order|level-order]
eval [post-order]
quit
> format in-order
> expr 1+4*3/2
> eval post-order
7
> quit
```

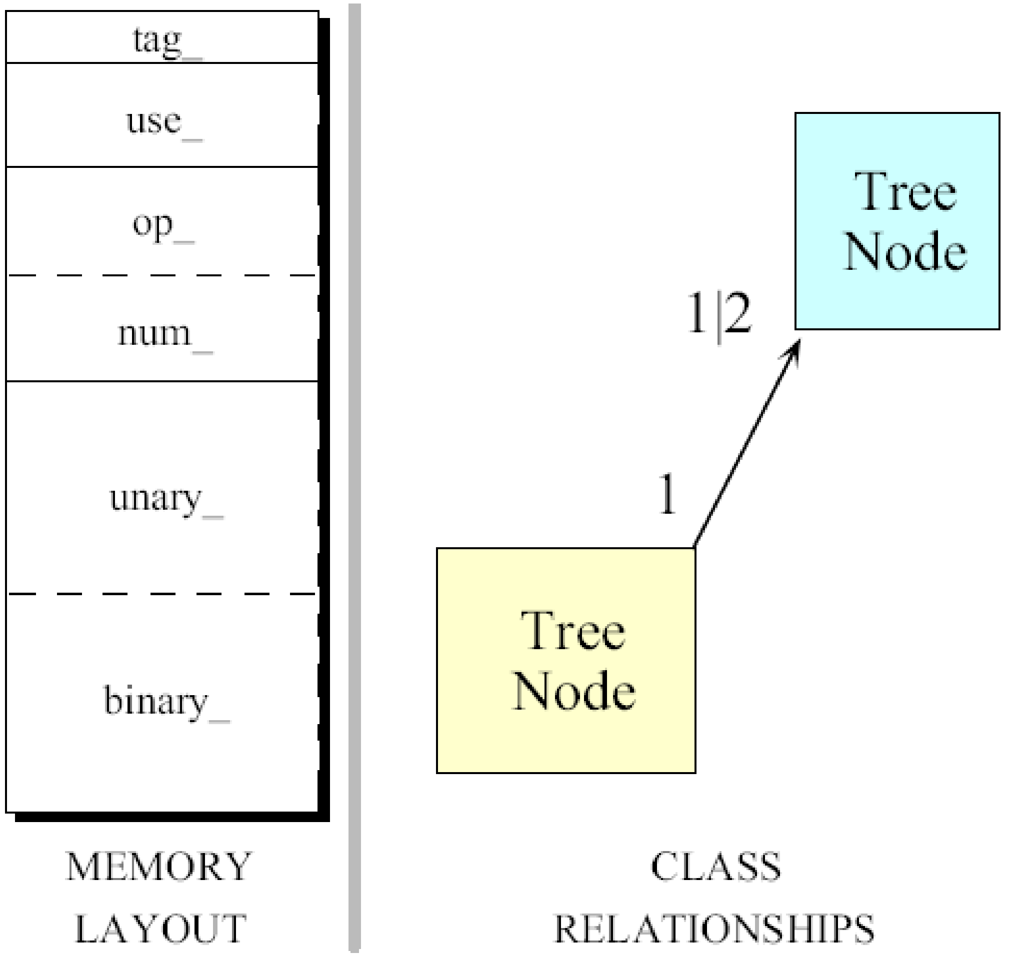
How *Not* to Design an Expression Tree Application

A typical algorithmic-based solution for implementing expression trees uses a C struct/union to represent the main data structure

```
typedef struct Tree_Node {
  enum { NUM, UNARY, BINARY } tag_;
  short use_; /* reference count */
  union {
    char op_[2];
    int num_;
  } o;
#define num_ o.num_
#define op_  o.op_
  union {
    struct Tree_Node *unary_;
    struct { struct Tree_Node *l_, *r_;} binary_;
  } c;
#define unary_ c.unary_
#define binary_ c.binary_
} Tree_Node;
```

How *Not* to Design an Expression Tree Application

Here's the memory layout & class diagram for a **`struct Tree_Node`**:



How *Not* to Design an Expression Tree Application

A typical algorithmic implementation uses a switch statement & a recursive function to build & evaluate a tree, e.g.:

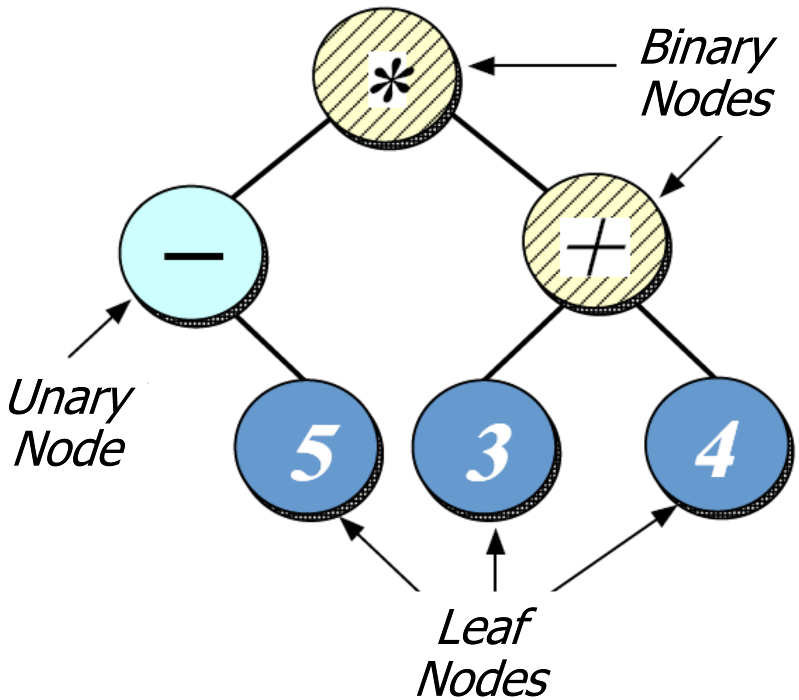
```
void print_tree (Tree_Node *root) {
  switch (root->tag_)
  case NUM: printf ("%d", root->num_); break;
  case UNARY:
    printf ("(%s", root->op_[0]);
    print_tree (root->unary_);
    printf (")"); break;
  case BINARY:
    printf ("(");
    print_tree (root->binary_.l_); // Recursive call
    printf ("%s", root->op_[0]);
    print_tree (root->binary_.r_); // Recursive call
    printf (")"); break;
  default:
    printf ("error, unknown type ");
}
```

Limitations with the Algorithmic Approach

- Little or no use of encapsulation: implementation details available to clients
- Incomplete modeling of the application domain, which results in
  - Tight coupling between nodes/edges in union representation
  - Complexity being in algorithms rather than the data structures, e.g., switch statements are used to select between various types of nodes in the expression trees
- Data structures are "passive" functions that do their work explicitly
- The program organization makes it hard to extend
  - e.g., Any small changes will ripple through entire design/implementation
- Easy to make mistakes switching on type tags
- Wastes space by making worst-case assumptions wrt structs & unions

An OO Alternative Using Patterns & Frameworks

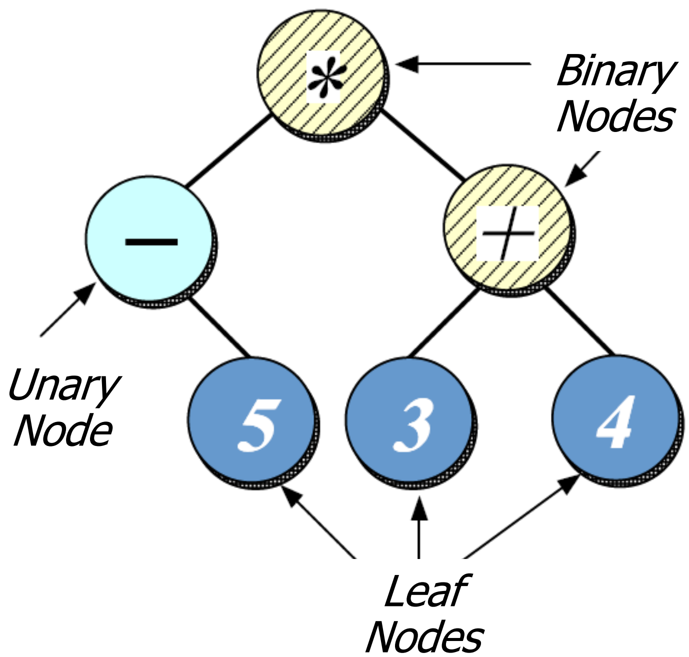
- Start with OO modeling of the "expression tree" application domain



- Model a *tree* as a collection of *nodes*
- *Nodes* are represented in an inheritance hierarchy that captures the particular properties of each node
  - e.g., precedence levels, different associativities, & different arities

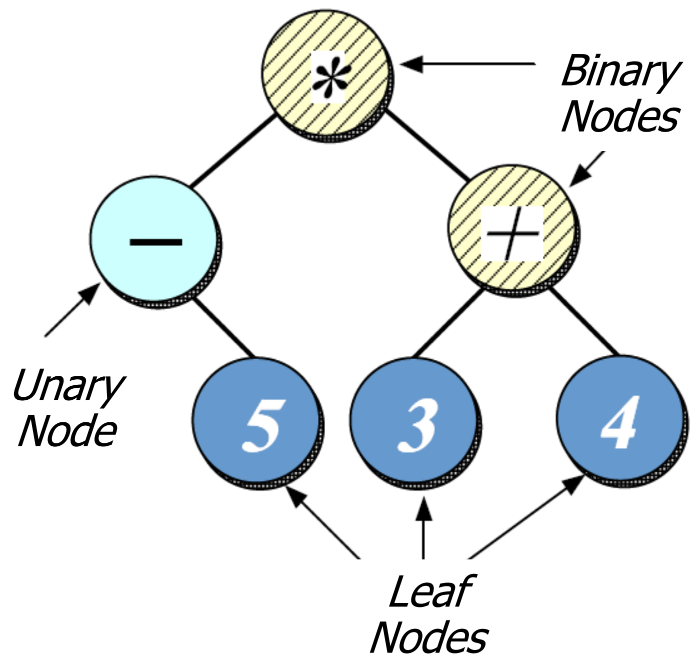
- Conduct *commonality/variability analysis* (CVA) to determine stable interfaces & points of variability
- Apply patterns to guide design/implementation of framework
- Integrate with C++ STL algorithms/containers where appropriate

Design Problems & Pattern-Oriented Solutions



Design Problem	Pattern(s)
Expression tree structure	Composite
Encapsulating variability & simplifying memory management	Bridge
Tree printing & evaluation	Iterator & Visitor
Consolidating user operations	Command
Ensuring correct protocol for commands	State
Consolidating creation of Variabilities	Abstract Factory & Factory Method
Parsing expressions & creating expression tree	Interpreter & Builder

Design Problems & Pattern-Oriented Solutions



Design Problem	Pattern(s)
Driving the application event flow	Reactor
Supporting multiple operation modes	Template Method & Strategy
Centralizing global objects effectively	Singleton
Implementing STL iterator semantics	Prototype
Eliminating loops via the STL `std::for_each()` algorithm	Adapter
Provide no-op commands	Null Object

None of these patterns are restricted to expression tree applications…

Managing Global Objects Effectively

Goals:

– Centralize access to objects that should be visible globally, e.g.:
  – command-line options that parameterize the behavior of the program
  – The object (Reactor) that drives the main event loop

Constraints/forces:

– Only need one instance of the command-line options & Reactor
– Global variables are problematic in C++

```
% tree-traversal -v
format [in-order]
expr [expression]
print [in-order|pre-order|post-order|level-order]
eval [post-order]
quit
> format in-order
> expr 1+4*3/2
> eval post-order
7
> quit

% tree-traversal
> 1+4*3/2
7
```

Verbose mode

Succinct mode

Solution: Centralize Access to Global Instances

Rather than using global variables, create a central access point to global instances, e.g.:

```
int main (int argc, char *argv[])
{
  // Parse the command-line options.
  if (!Options::instance ()->parse_args (argc, argv))
    return 0;

  // Dynamically allocate the appropriate event handler
  // based on the command-line options.
  Expression_Tree_Event_Handler *tree_event_handler =
    Expression_Tree_Event_Handler::make_handler
      (Options::instance ()->verbose ());

  // Register event handler with the reactor.
  Reactor::instance ()->register_input_handler
    (tree_event_handler);
  // ...
```

Singleton object creational

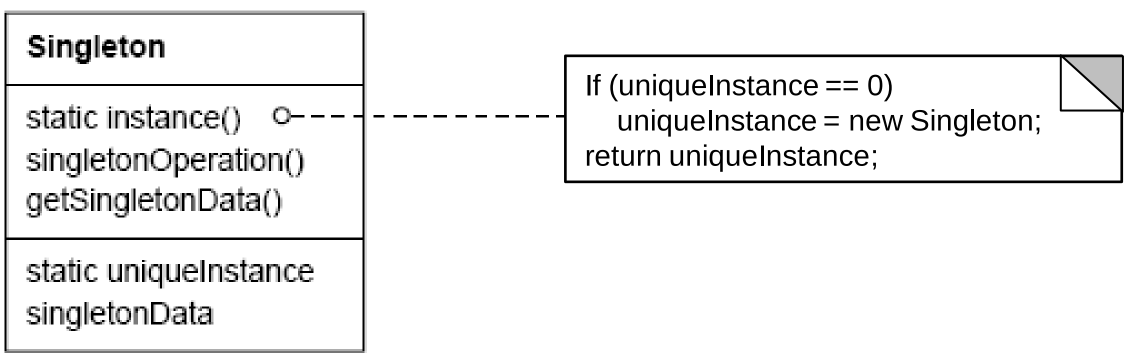
Intent

ensure a class only ever has one instance & provide a global point of access

Applicability

- when there must be exactly one instance of a class, & it must be accessible from a well-known access point
- when the sole instance should be extensible by subclassing, & clients should be able to use an extended instance without modifying their code

Structure



Singleton object creational

Consequences

+ reduces namespace pollution
+ makes it easy to change your mind & allow more than one instance
+ allow extension by subclassing
– same drawbacks of a global if misused
– implementation may be less efficient than a global
– concurrency pitfalls strategy creation & communication overhead

Implementation

– static instance operation
– registering the singleton instance
– deleting singletons

Known Uses

– Unidraw's Unidraw object
– Smalltalk-80 ChangeSet, the set of changes to code
– InterViews Session object

See Also

– Double-Checked Locking Optimization pattern from POSA2
– "To Kill a Singleton" www.research.ibm.com/designpatterns/pubs/ph-jun96.txt

Expression Tree Structure

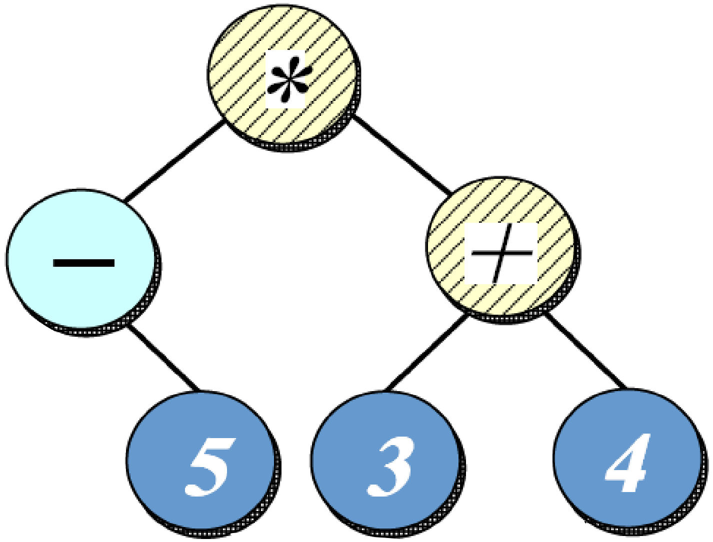
Goals:

– Support "physical" structure of expression tree

- e.g., binary/unary operators & operators

– Provide "hook" for enabling arbitrary operations on tree nodes

- Via Visitor pattern

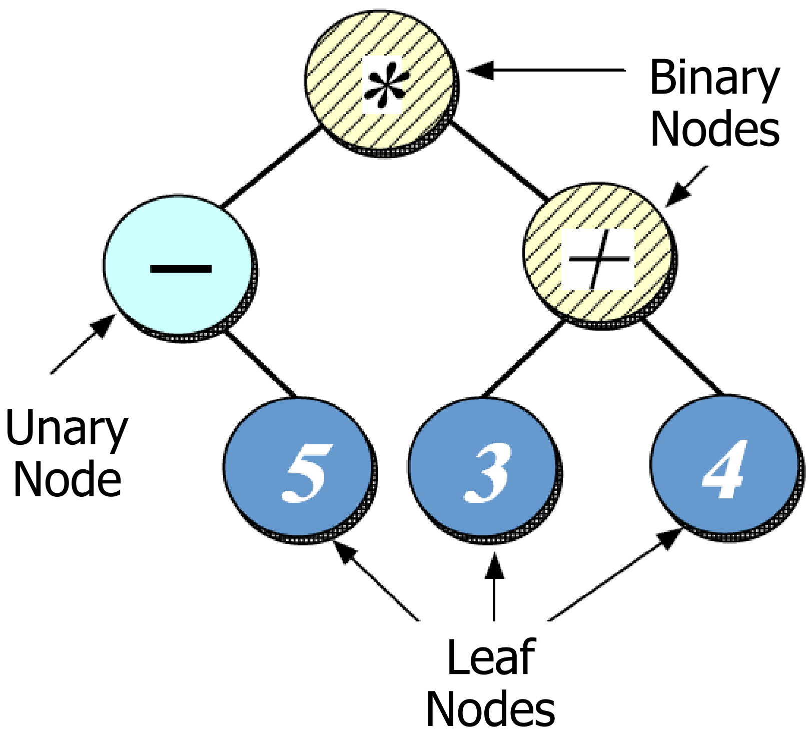


Constraints/forces:

– Treat operators & operands uniformly

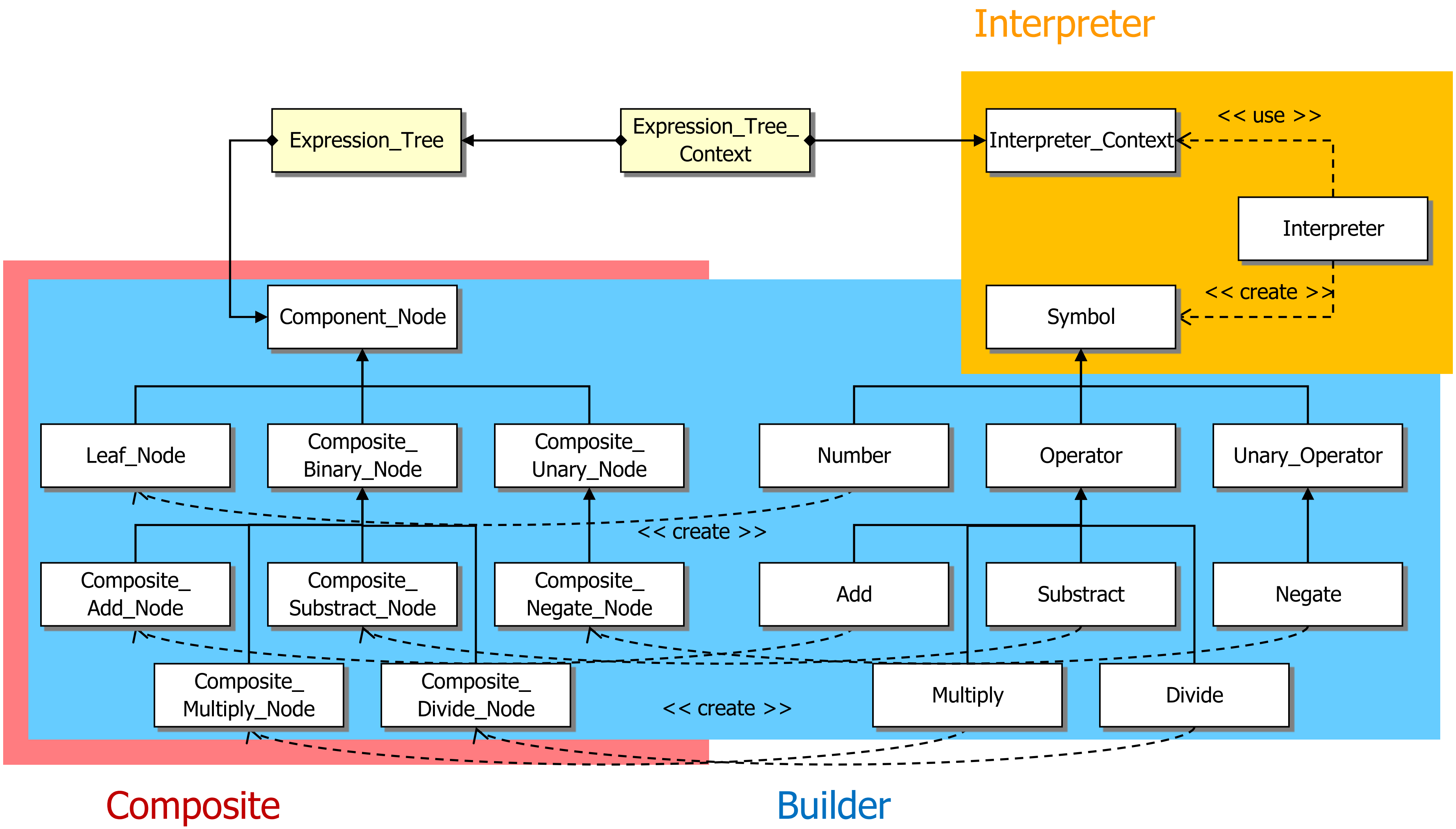
– No distinction between one & many

Solution: Recursive Structure



- Model a *tree* as a recursive collection of *nodes*
- *Nodes* are represented in an inheritance hierarchy that captures the particular properties of each node
  - e.g., precedence levels, different associativities, & different arities
- Binary nodes recursively contain two other nodes; unary nodes recursively contain one other node

Overview of Tree Structure & Creation Patterns



Component_Node

Abstract base class for composable expression tree node objects

Interface:

```
virtual ~Component_Node (void)=0
virtual int item (void) const
virtual Component_Node * left (void) const
virtual Component_Node * right (void) const
virtual void accept (Visitor &visitor) const
```

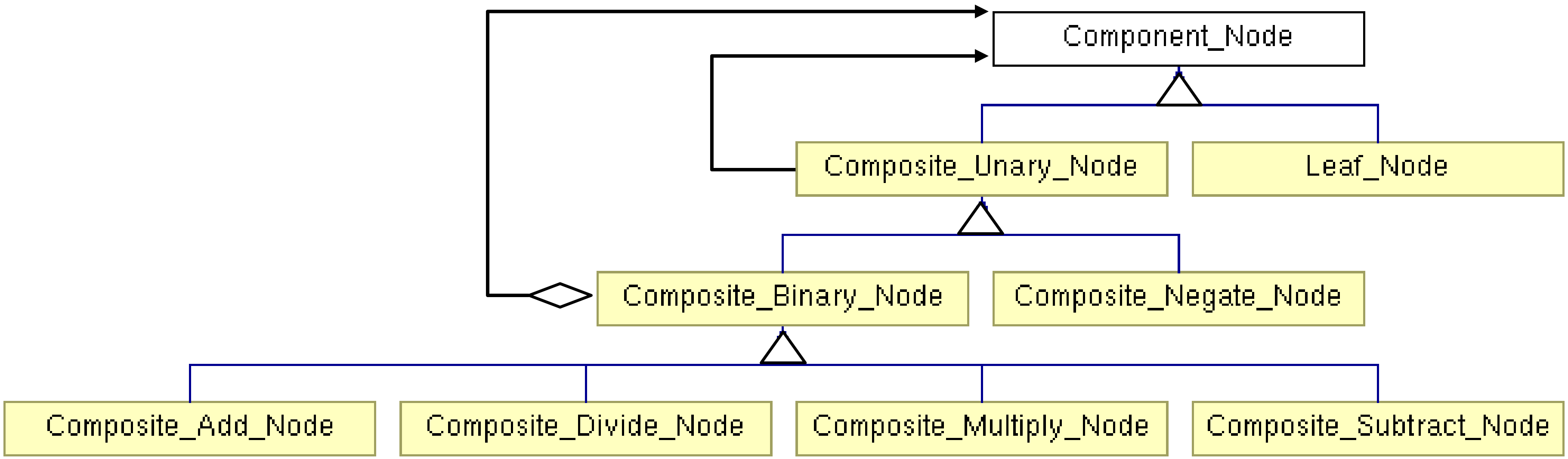
Subclasses:

`Leaf_Node`, **`Composite_Unary_Node`**, **`Composite_Binary_Node`**, etc.

Commonality: base class interface is used by all nodes in an expression tree

Variability: each subclass defines state & method implementations that are specific for the various types of nodes

Component_Node Hierarchy



Note the inherent recursion in this hierarchy

- i.e., a **`Composite_Binary_Node`** *is a* **`Component_Node`** & a **`Composite_Binary_Node`** also *has* **`Component_Node`**s!

Composite object structural

Intent

treat individual objects & multiple, recursively-composed objects uniformly

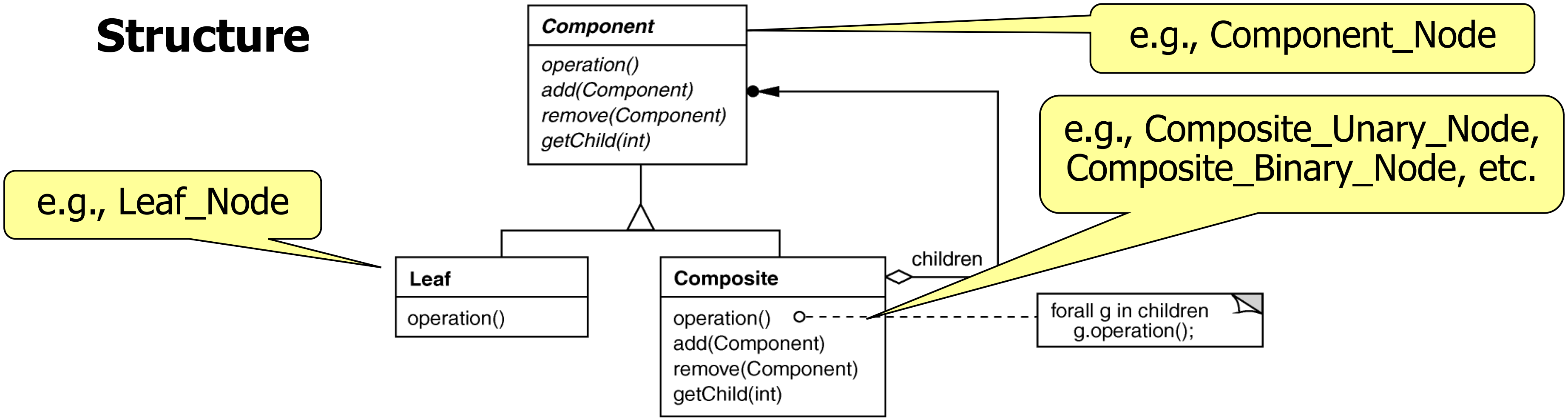
Applicability

objects must be composed recursively,

and no distinction between individual & composed elements,

and objects in structure can be treated uniformly

Structure



Composite object structural

Consequences

+ uniformity: treat components the same regardless of complexity
+ extensibility: new Component subclasses work wherever old ones do
– overhead: might need prohibitive numbers of objects
– Awkward designs: may need to treat leaves as lobotomized composites

Implementation

– do Components know their parents?
– uniform interface for both leaves & composites?
– don't allocate storage for children in Component base class
– responsibility for deleting children

Known Uses

– ET++ Vobjects
– InterViews Glyphs, Styles
– Unidraw Components, MacroCommands
– Directory structures on UNIX & Windows
– Naming Contexts in CORBA
– MIME types in SOAP

Parsing Expressions & Creating Expression Tree

Goals:

– Simplify & centralize the creation of all nodes in the composite expression tree

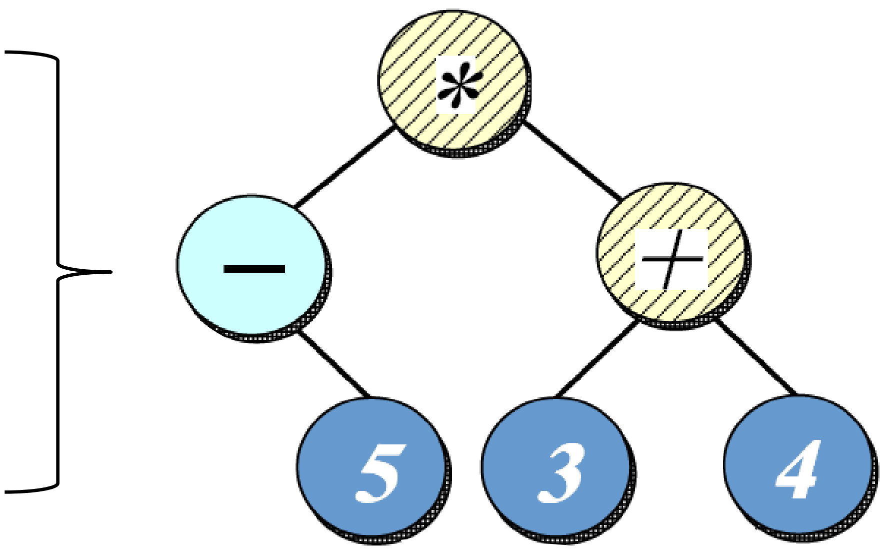
– Extensible for future types of expression orderings

Constraints/forces:

– Don’t recode existing clients

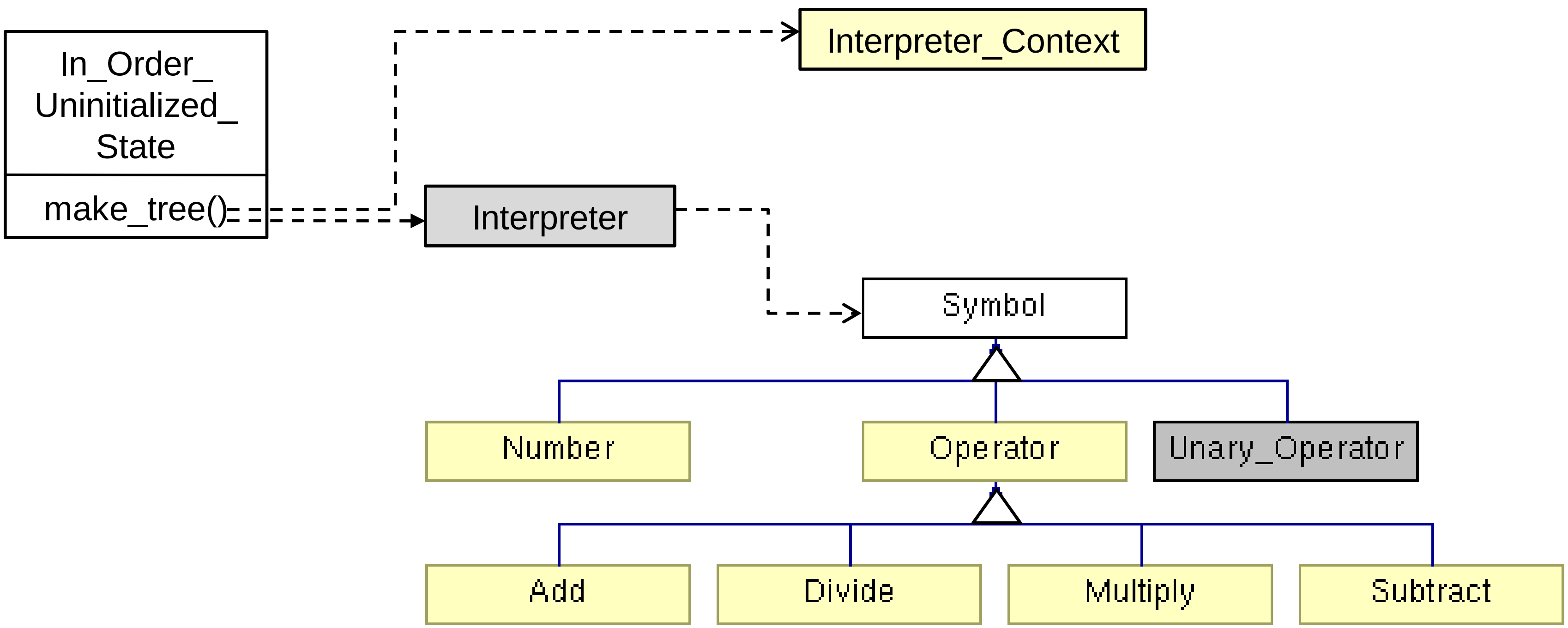
– Add new expressions without recompiling

“in-order” expression = -5*(3+4)
“pre-order” expression = *-5+34
“post-order” expression = 5-34+*
“level-order” expression = *-+534



Solution: Build Parse Tree Using Interpreter

- Each **`make_tree()`** method in the appropriate state object uses an interpreter to create a parse tree that corresponds to the expression input
- This parse tree is then traversed to build each node in the corresponding expression tree



Interpreter

Parses expressions into parse tree & generate corresponding expression tree

Interface:

```
Interpreter (void)
virtual ~Interpreter (void)
Expression_Tree interpret (Interpreter_Context &context,
                           const std::string &input)
```

uses

```
Interpreter_Context (void)
~Interpreter_Context (void)
int get (std::string variable)
void set (std::string variable, int value)
void print (void)
void reset (void)
```

creates

```
Symbol (Symbol *left,
        Symbol *right)
virtual ~Symbol (void)
virtual int precedence (void)=0
virtual Component_Node * build (void)=0
```

Commonality: Provides a common interface for parsing expression input & building expression trees

Variability: The structure of the expression trees can vary depending on the format & contents of the expression input

Interpreter class behavioral

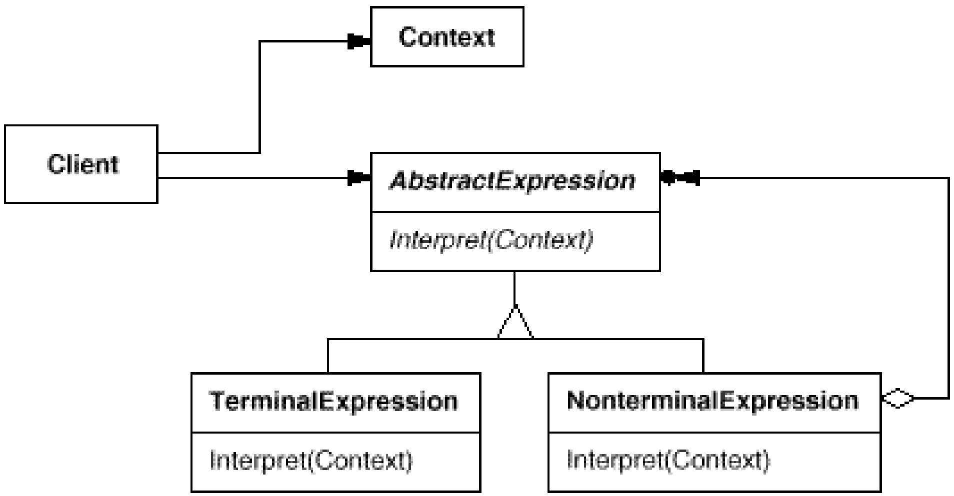
Intent

Given a language, define a representation for its grammar along with an interpreter that uses the representation to interpret sentences in the language

Applicability

- When the grammar is simple & relatively stable
- Efficiency is not a critical concern

Structure



Interpreter class behavioral

Consequences

+ Simple grammars are easy to change & extend, e.g., all rules represented by distinct classes in an orderly manner
+ Adding another rule adds another class
– Complex grammars are hard to implement & maintain, e.g., more interdependent rules yield more interdependent classes

Implementation

- Express the language rules, one per class
- Alternations, repetitions, or sequences expressed as *nonterminal expresssions*
- Literal translations expressed as *terminal expressions*
- Create interpret method to lead the context through the interpretation classes

Known Uses

- Text editors &Web browsers use Interpreter to lay out documents & check spelling
- For example, an equation in TeX is represented as a tree where internal nodes are operators, e.g. square root, & leaves are variables

Builder   object creational

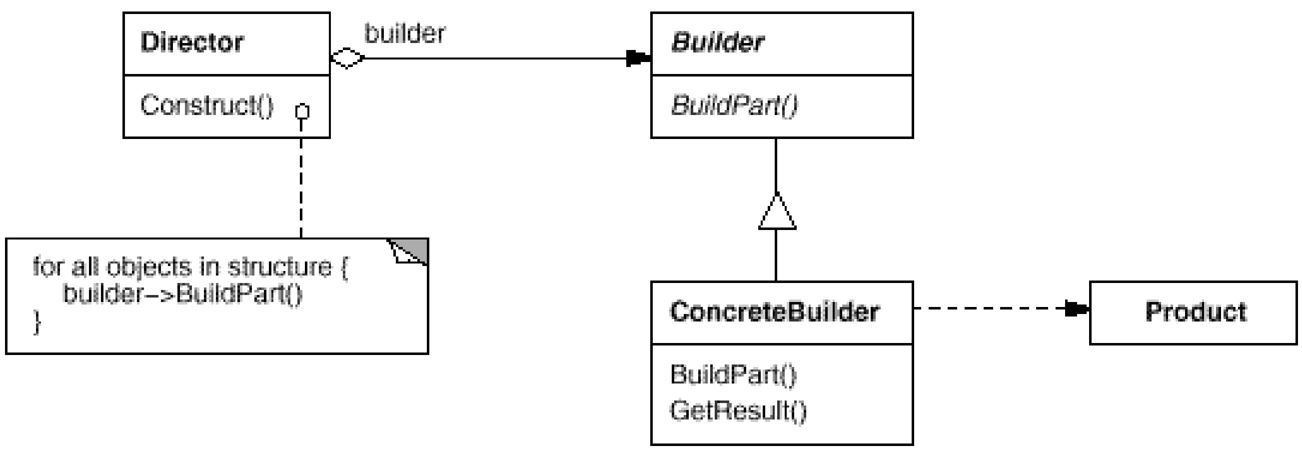
Intent

Separate the construction of a complex object from its representation so that the same construction process can create different representations

Applicability

- Need to isolate knowledge of the creation of a complex object from its parts
- Need to allow different implementations/interfaces of an object's parts

Structure



Builder object creational

Consequences

+ Can vary a product's internal representation
+ Isolates code for construction & representation
+ Finer control over the construction process

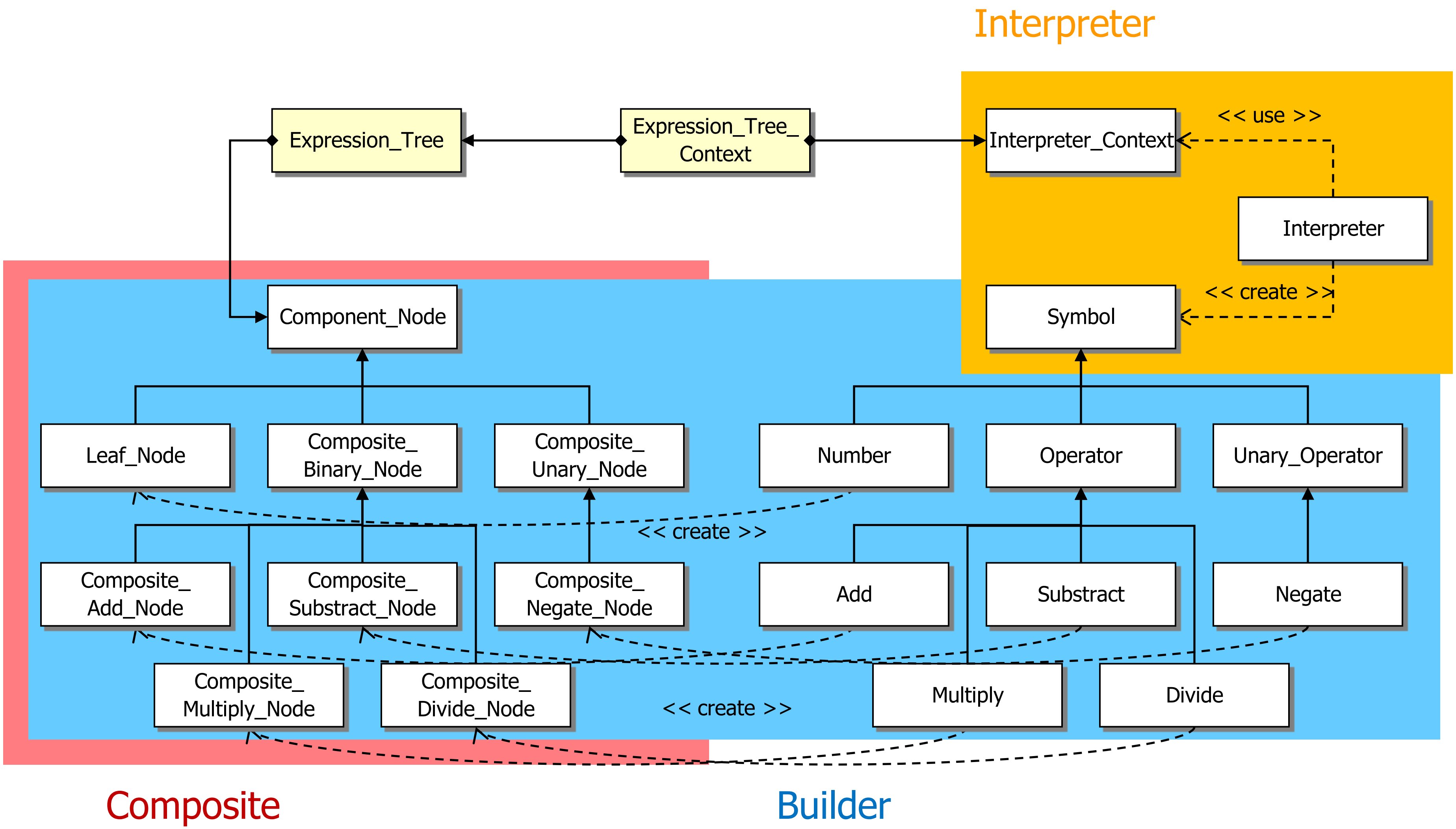
Implementation

- The Builder pattern is basically a Factory pattern with a mission
- A Builder pattern implementation exposes itself as a factory, but goes beyond the factory implementation in that various implementations are wired together

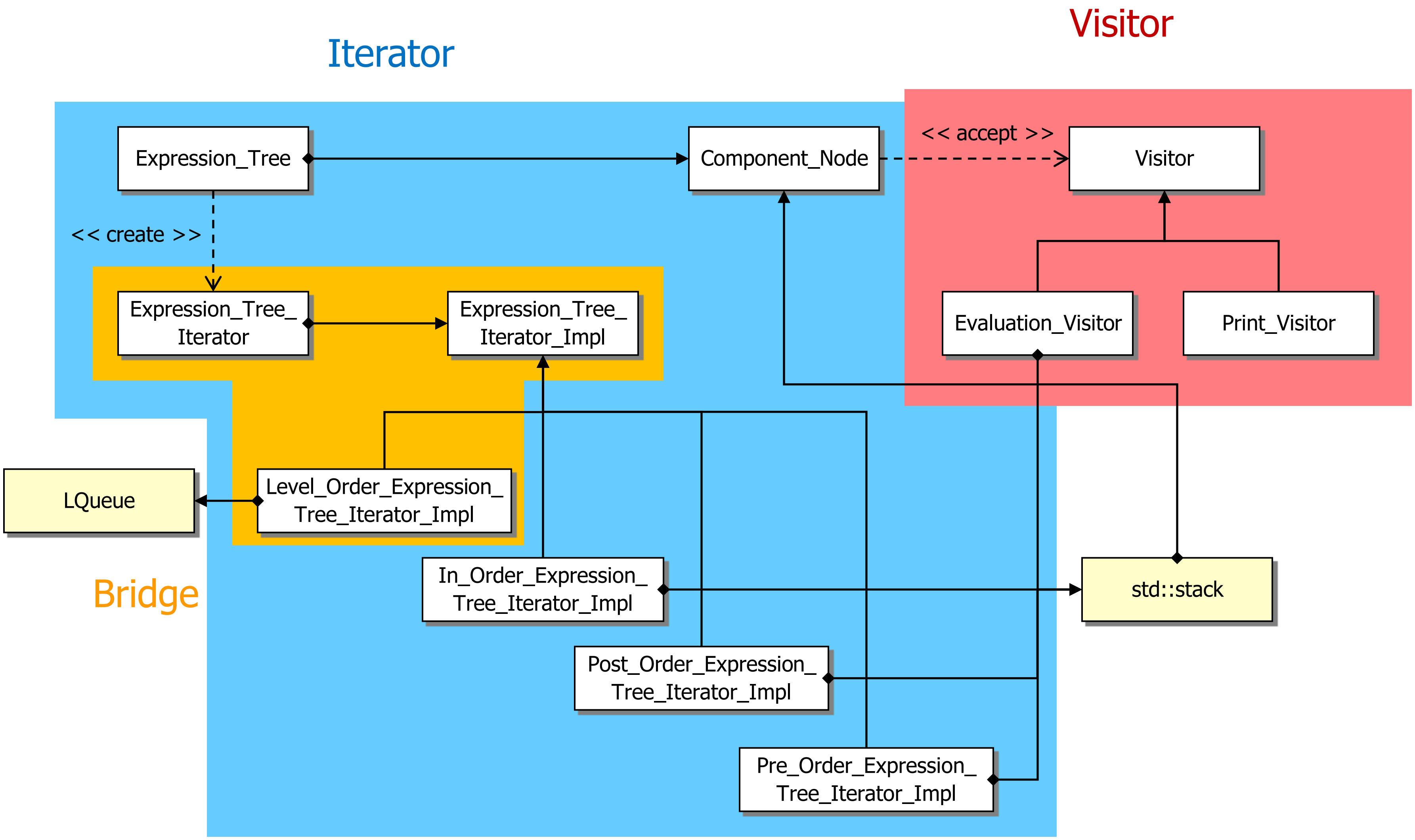
Known Uses

- ACE Service Configurator framework

Summary of Tree Structure & Creation Patterns



Overview of Tree Traversal Patterns



Encapsulating Variability & Simplifying Memory Managment

Goals

- Hide many sources of variability in expression tree construction & use
- Simplify C++ memory management, i.e., minimize use of new/delete in application code

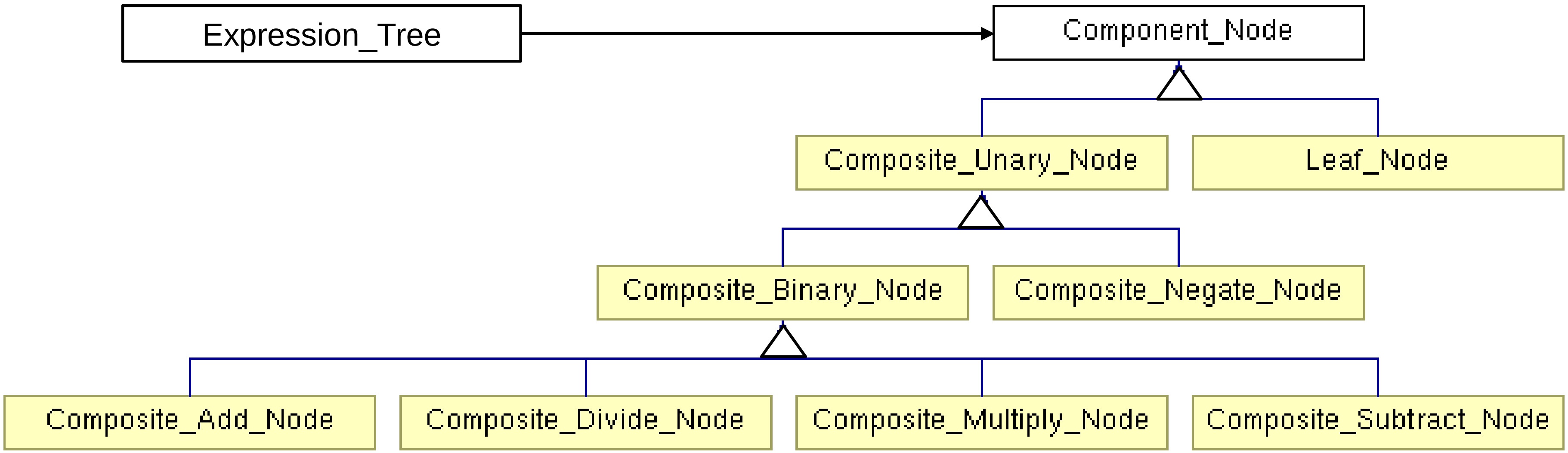
Constraints/forces:

- Must account for the fact that STL algorithms & iterators have "value semantics"

```
for (Expression_Tree::iterator iter = tree.begin ();
     iter != tree.end ();
     ++iter)
  (*iter).accept (print_visitor);
```

- Must ensure that exceptions don't cause memory leaks

Solution: Decouple Interface & Implementation(s)



- Create a public interface class (**`Expression_Tree`**) used by clients & a private implementation hierarchy (rooted at **`Component_Node`**) that encapsulates variability
  - The public interface class can perform reference counting of implementation object(s) to automate memory management
- An Abstract Factory can produce the right implementation (as seen later)

Expression_Tree

Interface for Composite pattern used to contain all nodes in expression tree

Interface:

```
                   Expression_Tree (void)
                   Expression_Tree (Component_Node *root)
                   Expression_Tree (const Expression_Tree &t)
              void operator= (const Expression_Tree &t)
                   ~Expression_Tree (void)
  Component_Node * get_root (void)
              bool is_null (void) const
         const int item (void) const
   Expression_Tree left (void)
   Expression_Tree right (void)
          iterator begin (const std::string &traversal_order)
          iterator end (const std::string &traversal_order)
    const_iterator begin (const std::string &traversal_order) const
    const_iterator end (const std::string &traversal_order) const
```

Commonality: Provides a common interface for expression tree operations

Variability: The contents of the expression tree nodes can vary depending on the expression

Bridge object structural

Intent

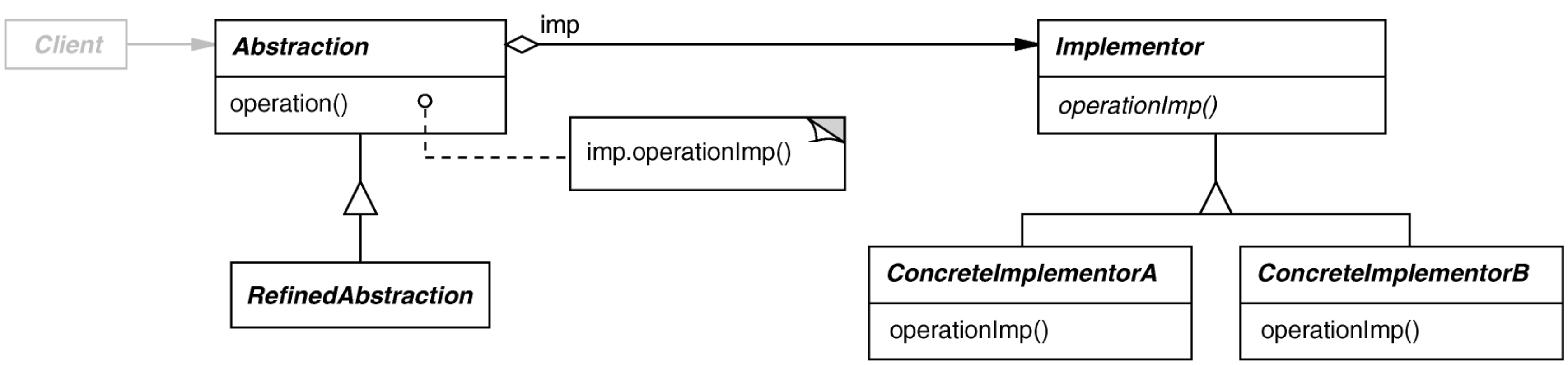
Separate a (logical) abstraction interface from its (physical) implementation(s)

Applicability

– When interface & implementation should vary independently

– Require a uniform interface to interchangeable class hierarchies

Structure



Bridge object structural

Consequences

+ abstraction interface & implementation are independent
+ implementations can vary dynamically
+ Can be used transparently with STL algorithms & containers
– one-size-fits-all Abstraction & Implementor interfaces

Implementation

- sharing Implementors & reference counting
  - See reusable **`Refcounter`** template class (based on STL/boost **`shared_pointer`**)
- creating the right Implementor (often use factories)

Known Uses

- ET++ Window/WindowPort
- libg++ Set/{LinkedList, HashTable}
- AWT Component/ComponentPeer

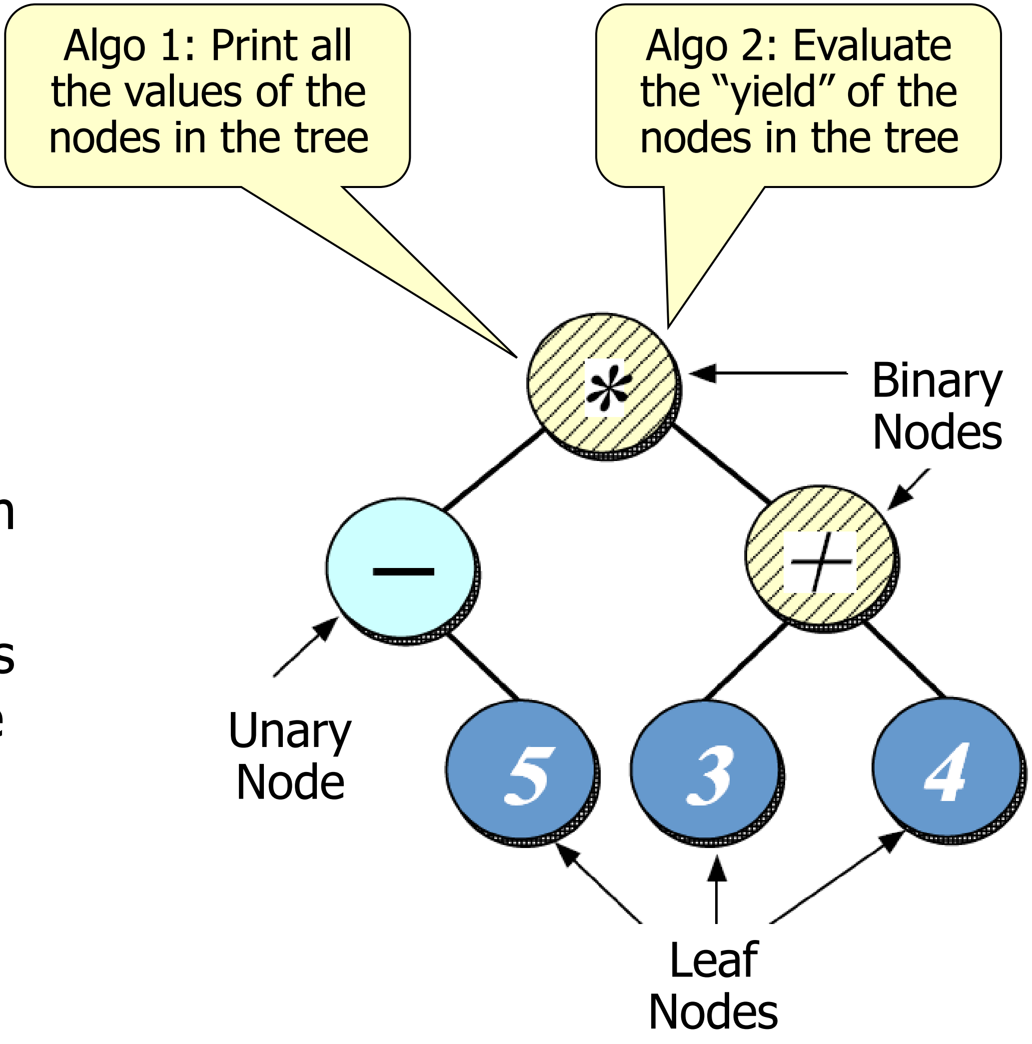
Tree Printing & Evaluation

Goals:

- Create a framework for performing algorithms that affect nodes in a tree

Constraints/forces:

- support multiple algorithms that can act on the expression tree
- don't tightly couple algorithms with expression tree structure
  - e.g., don't have "print" & "evaluate" methods in the node classes



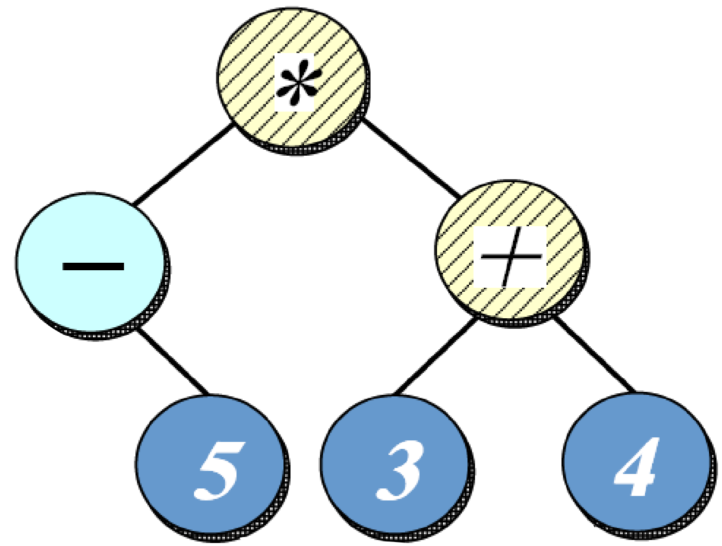
Solution: Encapsulate Traversal

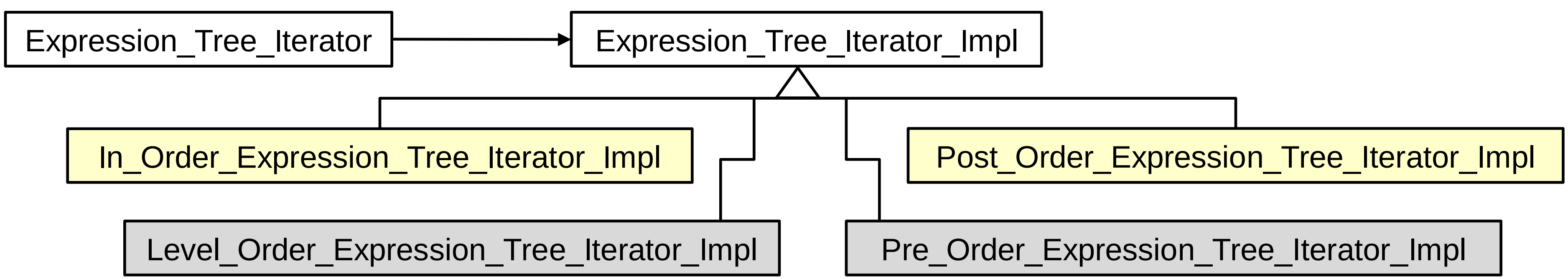
Iterator

- encapsulates a traversal algorithm without exposing representation details to callers

e.g.,

- “in-order iterator” = -5*(3+4)
- “pre-order iterator” = *-5+34
- “post-order iterator” = 5-34+*
- “level-order iterator” = *-+534





Note use of the Bridge pattern to encapsulate variability

Expression_Tree_Iterator

Interface for Iterator pattern that traverses all nodes in tree expression

Interface:

```
                 Expression_Tree_Iterator
                       (const Expression_Tree_Iterator &)
                 Expression_Tree_Iterator
                       (Expression_Tree_Iterator_Impl *)
   Expression_Tree operator * (void)
   const Expression_Tree operator * (void) const
Expression_Tree_Iterator & operator++ (void)
 Expression_Tree_Iterator operator++ (int)
                    bool operator== (const Expression_Tree_Iterator &rhs)
                    bool operator!= (const Expression_Tree_Iterator &rhs)
```

Commonality: Provides a common interface for expression tree iterators that conforms to the standard STL iterator interface

Variability: Can be configured with specific expression tree iterator algorithms via the Bridge & Abstract Factory patterns

See Expression_Tree_State.cpp for example usage

Expression_Tree_Iterator_Impl

Implementation of the Iterator pattern that is used to define the various iterations algorithms that can be performed to traverse the expression tree

Interface:

```
                                        Expression_Tree_Iterator_Impl (const
                                        Expression_Tree &tree)
                                virtual ~Expression_Tree_Iterator_Impl (void)
                virtual Expression_Tree operator * (void) =0
          virtual const Expression_Tree operator * (void) const =0
                           virtual void operator++ (void)=0
                           virtual bool operator== (const
                                        Expression_Tree_Iterator_Impl &rhs) const =0
                           virtual bool operator!= (const
                                        Expression_Tree_Iterator_Impl &rhs) const =0
virtual Expression_Tree_Iterator_Impl * clone (void)=0
```

Commonality: Provides a common interface for implementing expression tree iterators that conforms to the standard STL iterator interface

Variability: Can be subclasses to define various algorithms for accessing nodes in the expression trees in a particular traversal order

Iterator object behavioral

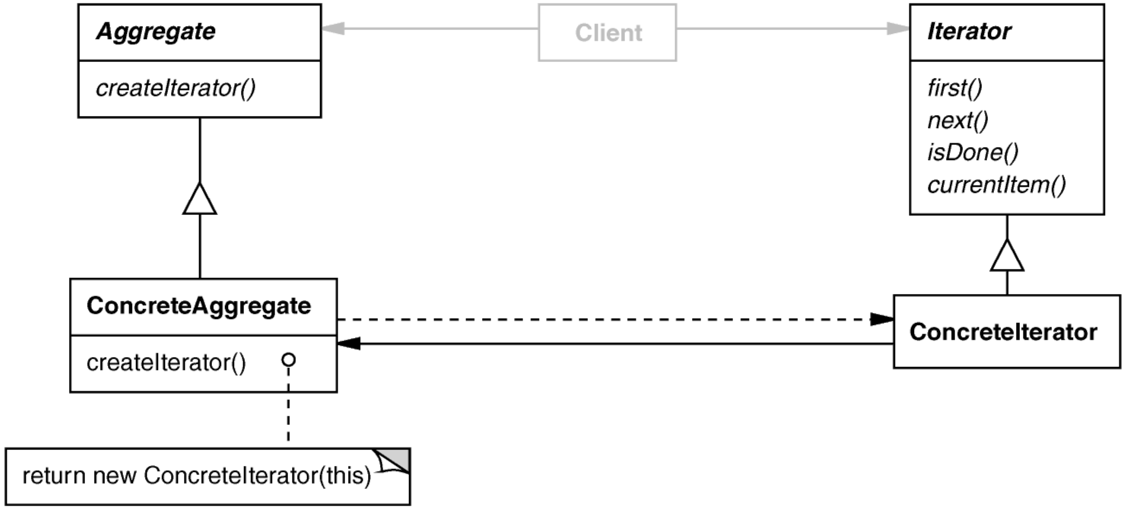
Intent

access elements of a aggregate (container) without exposing its representation

Applicability

– require multiple traversal algorithms over an aggregate
– require a uniform traversal interface over different aggregates
– when aggregate classes & traversal algorithm must vary independently

Structure



Comparing STL Iterators with GoF Iterators

STL iterators have "value-semantics", e.g.:

```
for (Expression_Tree::iterator iter = tree.begin (" Level Order" );
     iter != tree.end (" Level Order" );
     ++iter)
  (*iter).accept (print_visitor);
```

In contrast, "GoF iterators have "pointer semantics", e.g.:

```
iterator *iter;

for (iter = tree.createIterator (" Level Order" );
     iter->done () == false;
     iter->advance ())
  (iter->currentElement ())->accept (print_visitor);

delete iter;
```

Bridge pattern simplifies use of STL iterators in expression tree application

Iterator object behavioral

Consequences

+ flexibility: aggregate & traversal are independent
+ multiple iterators & multiple traversal algorithms
– additional communication overhead between iterator & aggregate
  – This is particularly problematic for iterators in concurrent or distributed systems

Implementation

- internal versus external iterators
- violating the object structure's encapsulation
- robust iterators
- synchronization overhead in multi-threaded programs
- batching in distributed & concurrent programs

Known Uses

- C++ STL iterators
- JDK Enumeration, Iterator
- Unidraw Iterator

Visitor

- Defines action(s) at each step of traversal & avoids wiring action(s) in nodes
- Iterator calls nodes's `accept(Visitor)` at each node, e.g.:

```
void Leaf_Node::accept (Visitor &v) { v.visit (*this); }
```

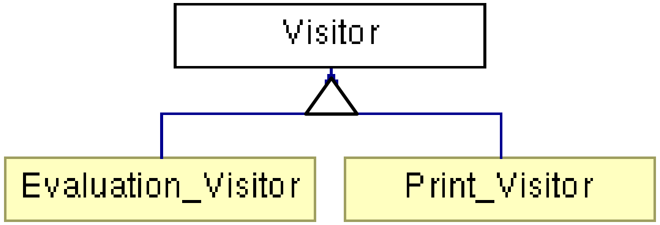
- `accept()` calls back on visitor using "static polymorphism"

Interface:

virtual void visit (const Leaf_Node &node)=0
virtual void visit (const Composite_Negate_Node &node)=0
virtual void visit (const Composite_Add_Node &node)=0
virtual void visit (const Composite_Subtract_Node &node)=0
virtual void visit (const Composite_Divide_Node &node)=0
virtual void visit (const Composite_Multiply_Node &node)=0

Commonality: Provides a common accept() method for all expression tree nodes & common `visit()` method for all visitor subclasses

Variability: Can be subclassed to define specific behaviors for the visitors & nodes



Print_Visitor

- Prints character code or value for each node

```
class Print_Visitor : public Visitor {
public:
    virtual void visit (const Leaf_Node &);
    virtual void visit (const Add_Node &);
    virtual void visit (const Divide_Node &);
    // etc. for all relevant Component_Node subclasses
};
```

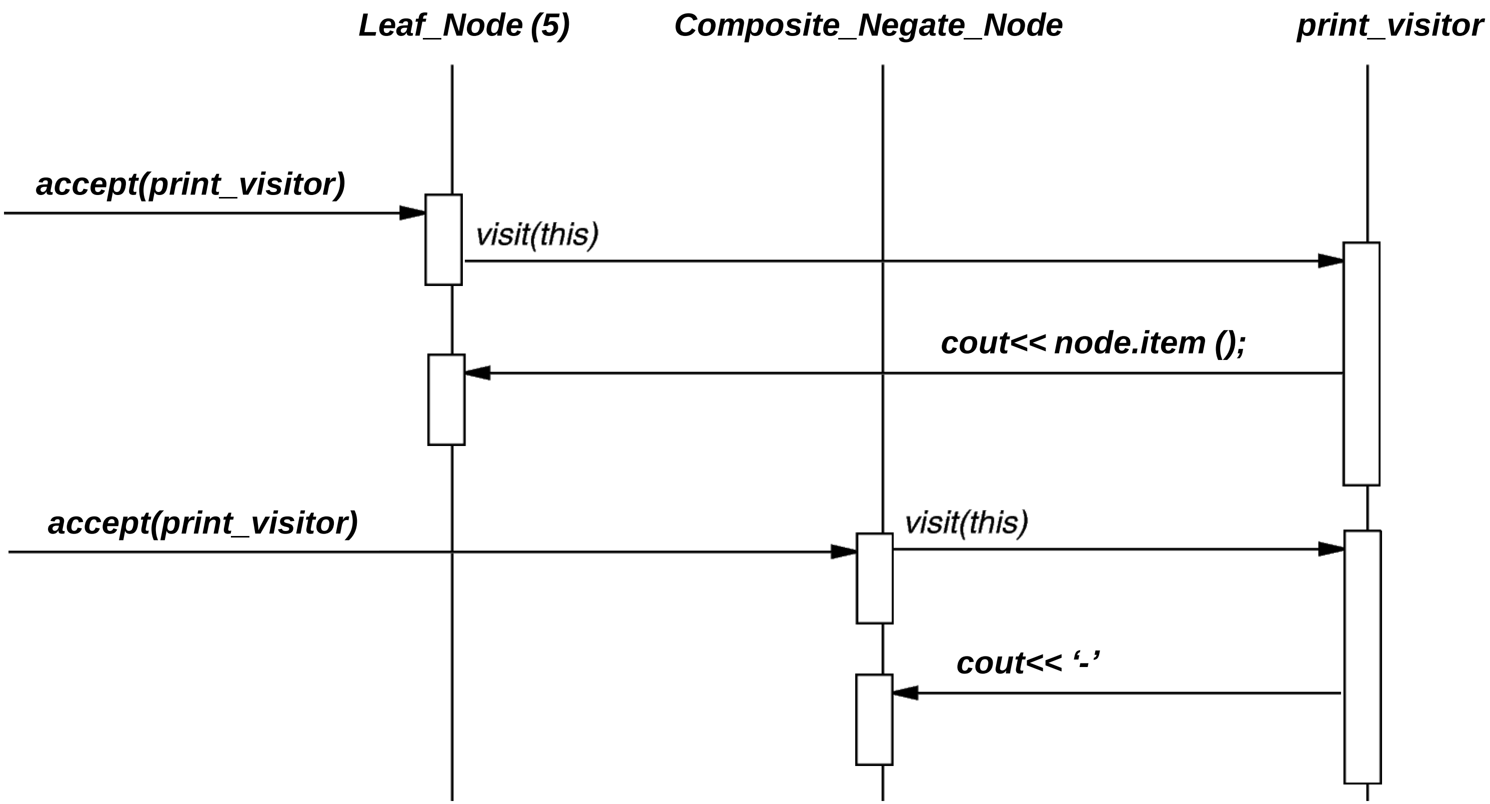
- Can be combined with any traversal algorithm, e.g.:

```
Print_Visitor print_visitor;
for (Expression_Tree::iterator iter =
       tree.begin ("post-order");
     iter != tree.end ("post-order");
     ++iter)
  (*iter).accept (print_visitor); // calls visit (*this);
```

See Expression_Tree_State.cpp for example usage

Print_Visitor Interaction Diagram

- The iterator controls the order in which `accept()` is called on each node in the composition
- `accept()` then "visits" the node to perform the desired *print* action

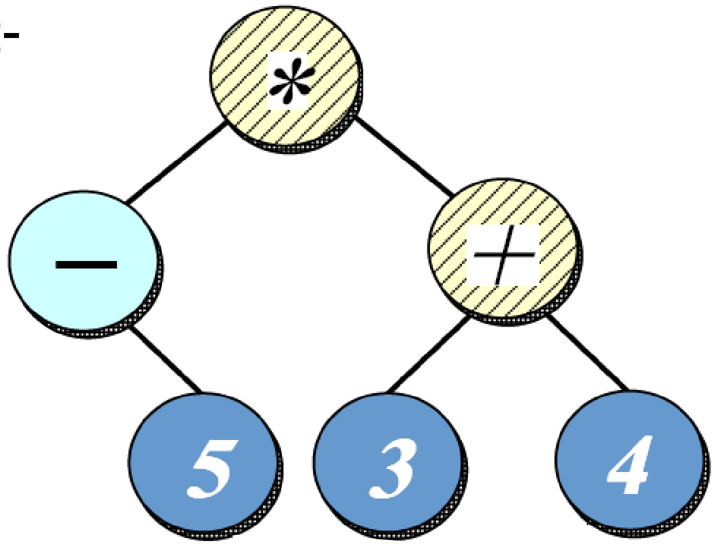


Evaluation_Visitor

- This class serves as a visitor for evaluating nodes in an expression tree that is being traversed using a post-order iterator
  - e.g., 5-34+*

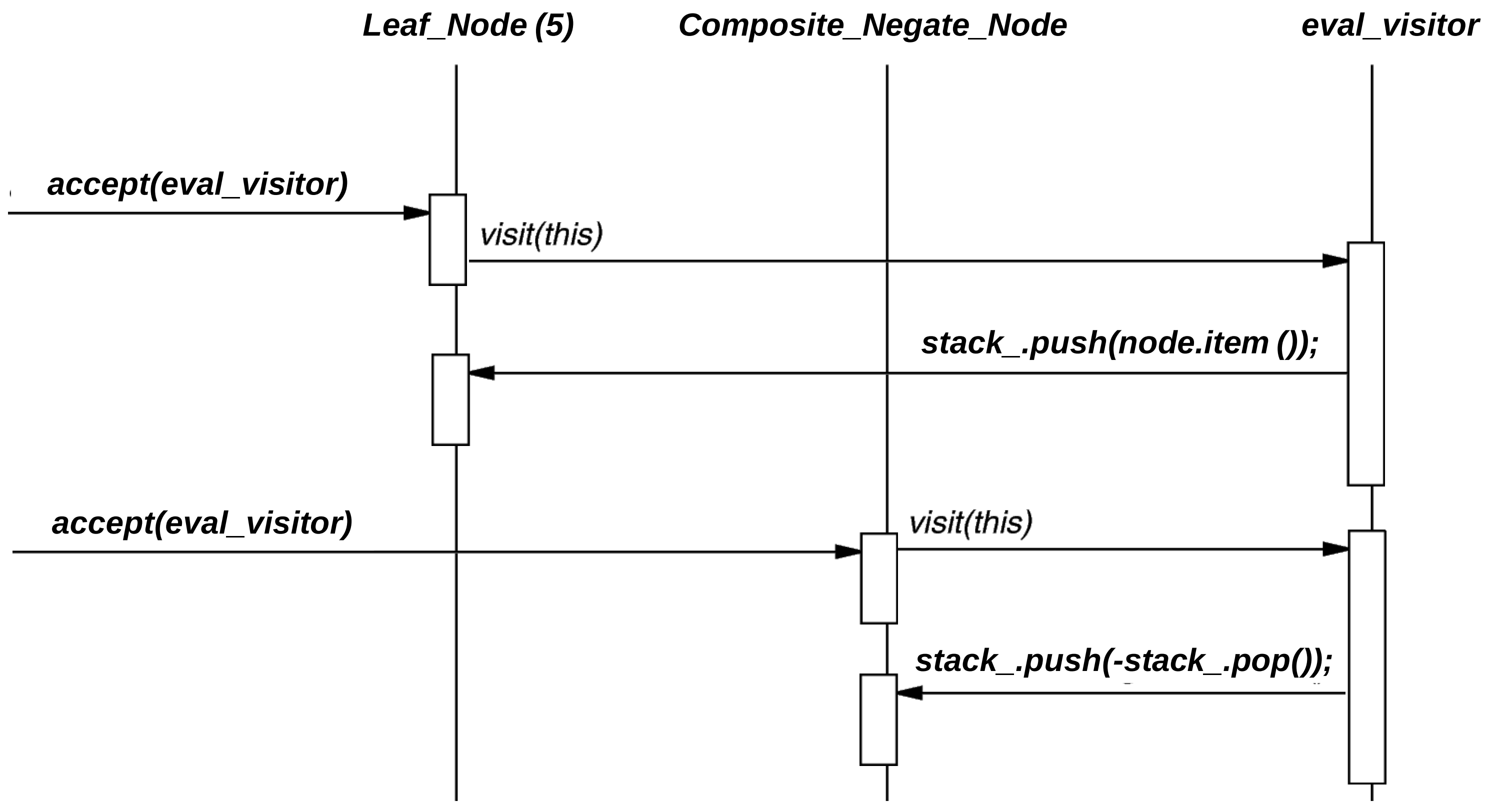
```
class Evaluation_Visitor :
  public Visitor { /* ... */ };
```

- It uses a stack to keep track of the post-order expression tree value that has been processed thus far during the iteration traversal, e.g.:
  1. S = [5] `push(node.item())`
  2. S = [-5] `push(-pop())`
  3. S = [-5, 3] `push(node.item())`
  4. S = [-5, 3, 4] `push(node.item())`
  5. S = [-5, 7] `push(pop()+pop())`
  6. S = [-35] `push(pop()*pop())`



Evaluation_Visitor Interaction Diagram

- The iterator controls the order in which `accept()` is called on each node in the composition
- `accept()` then "visits" the node to perform the desired *evaluation* action



Visitor object behavioral

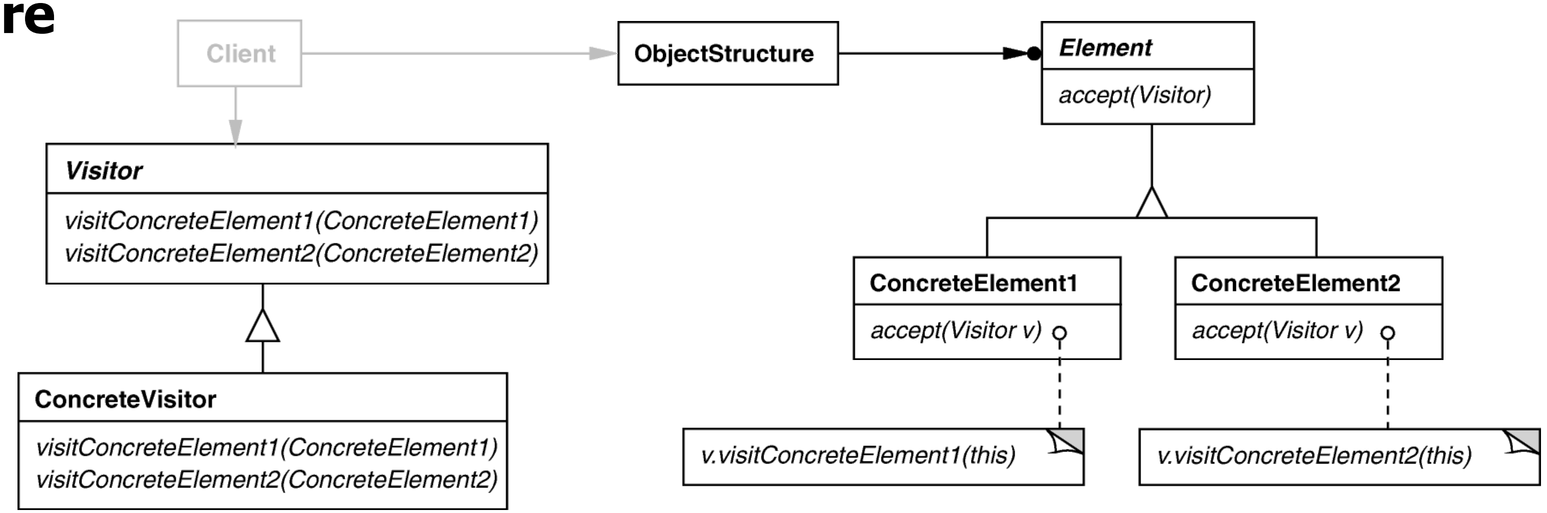
Intent

Centralize operations on an object structure so that they can vary independently but still behave polymorphically

Applicability

- when classes define many unrelated operations
- class relationships of objects in the structure rarely change, but the operations on them change often
- algorithms keep state that's updated during traversal

Structure



Note "static polymorphism" based on method overloading by type

Visitor object behavioral

Consequences

+ flexibility: visitor algorithm(s) & object structure are independent
+ localized functionality in the visitor subclass instance
– circular dependency between Visitor & Element interfaces
– Visitor brittle to new ConcreteElement classes

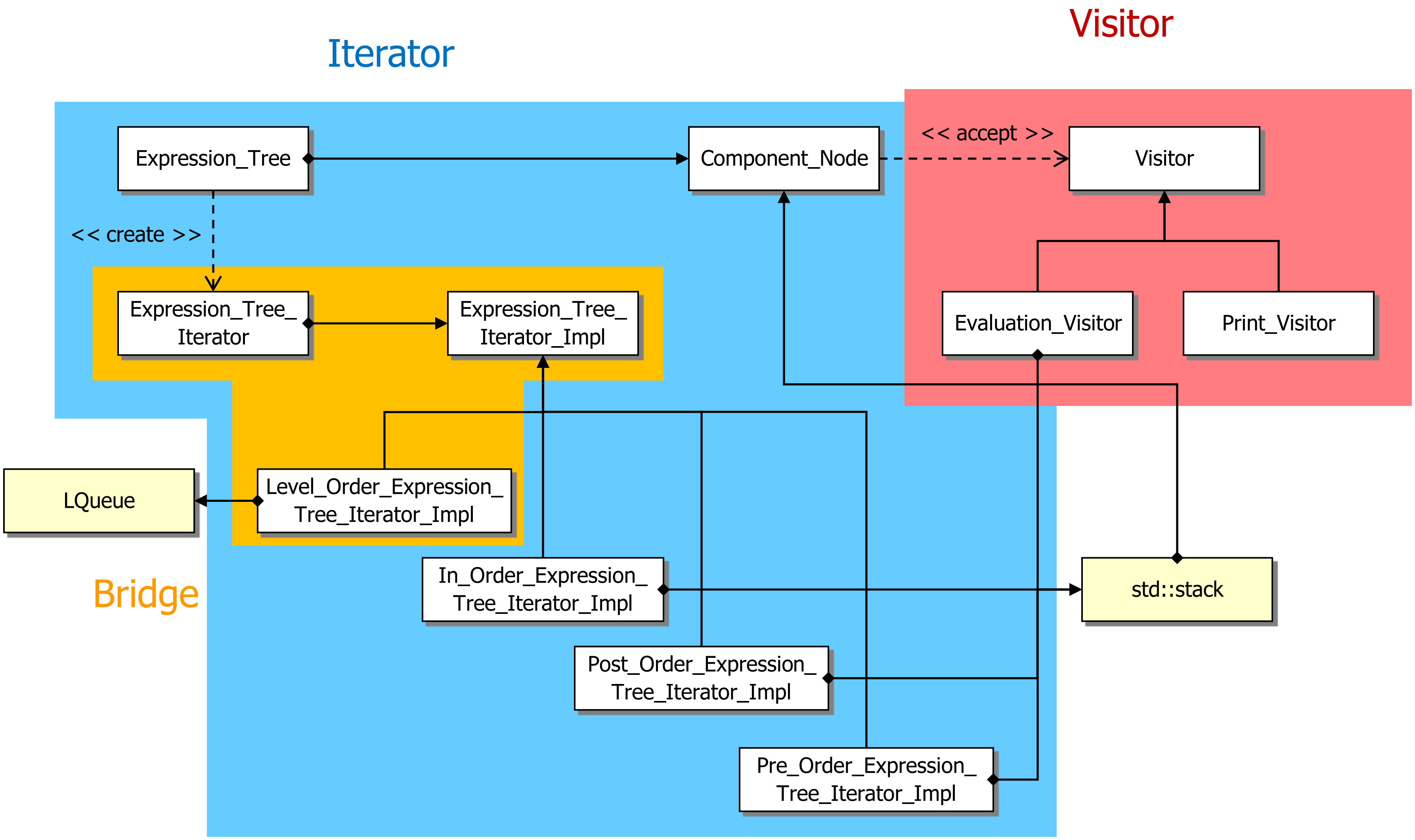
Implementation

- double dispatch
- general interface to elements of object structure

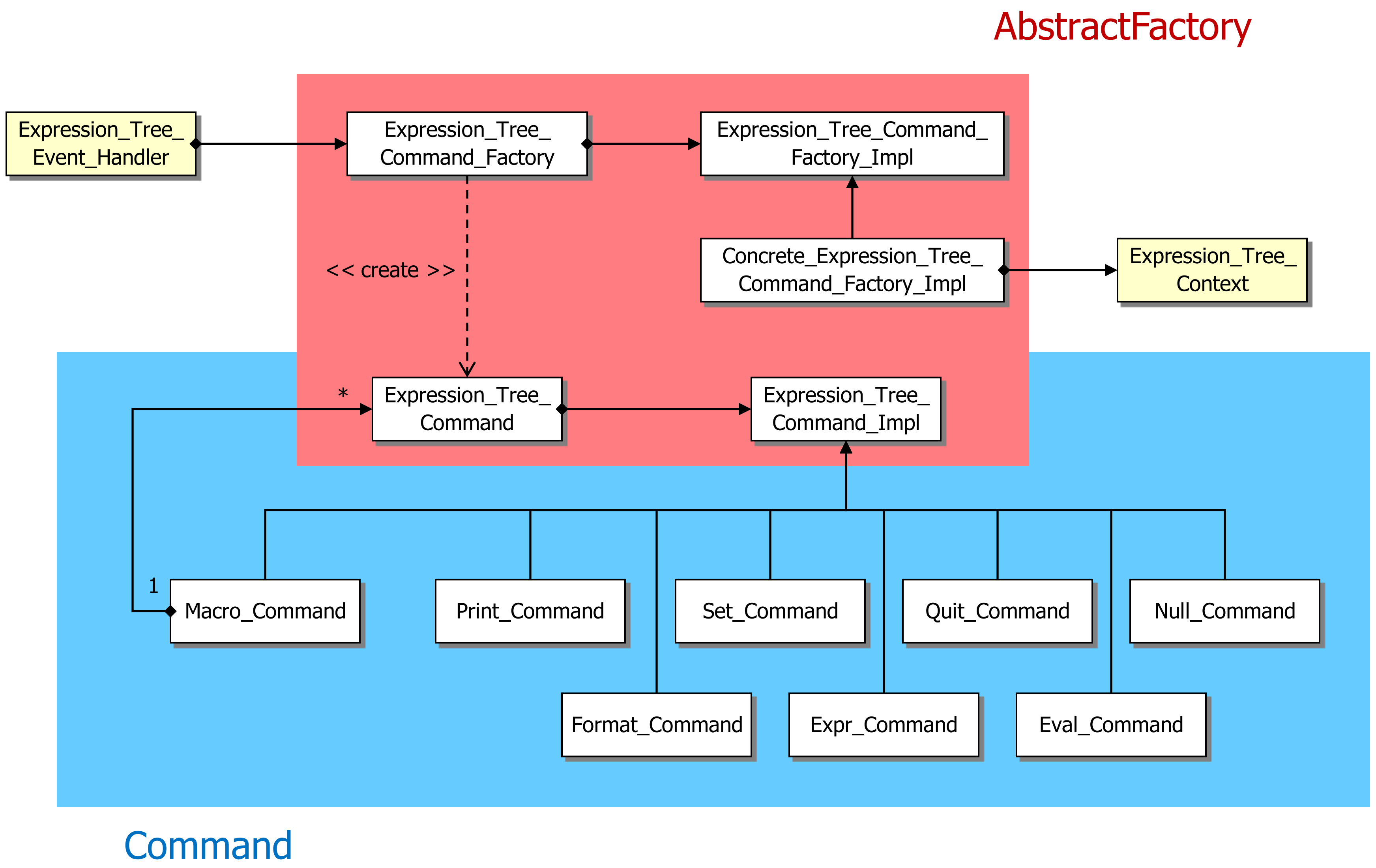
Known Uses

- ProgramNodeEnumerator in Smalltalk-80 compiler
- IRIS Inventor scene rendering
- TAO IDL compiler to handle different backends

Summary of Tree Traversal Patterns



Overview of Command & Factory Patterns



Consolidating User Operations

Goals:

- support execution of user operations
- support macro commands
- support undo/redo

Constraints/forces:

- scattered operation implementations
- Consistent memory management

```
% tree-traversal -v
format [in-order]
expr [expression]
print [in-order|pre-order|post-order|level-order]
eval [post-order]
quit
> format in-order
> expr 1+2*3/2
> print in-order
1+2*3/2
> print pre-order
+1/*232
> eval post-order
4
> quit
```

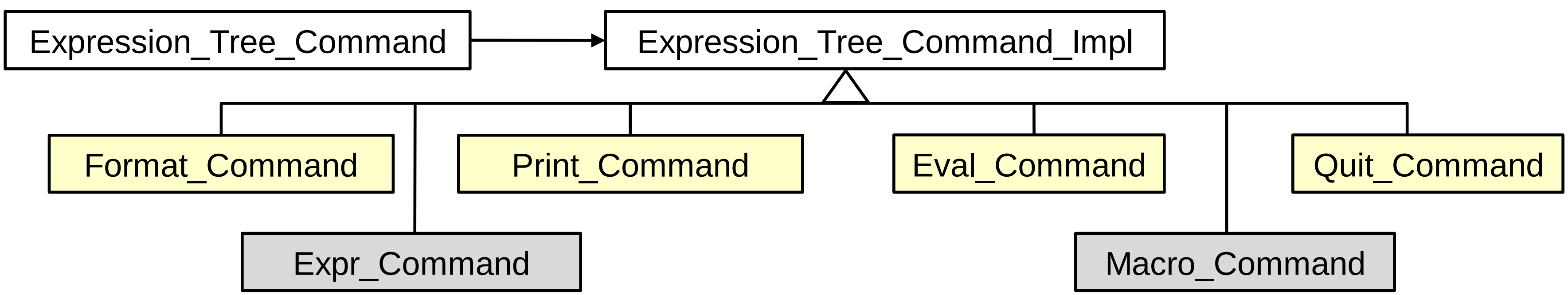
Solution: Encapsulate Each Request w/Command

A **Command** encapsulates

- an operation (`execute()`)
- an inverse operation (`unexecute()`)
- a operation for testing reversibility (`boolean reversible()`)
- state for (un)doing the operation

Command may

- implement the operations itself, *or*
- delegate them to other object(s)



Note use of Bridge pattern to encapsulate variability & simplify memory management

Expression_Tree_Command

Interface for Command pattern used to define a command that performs an operation on the expression tree when executed

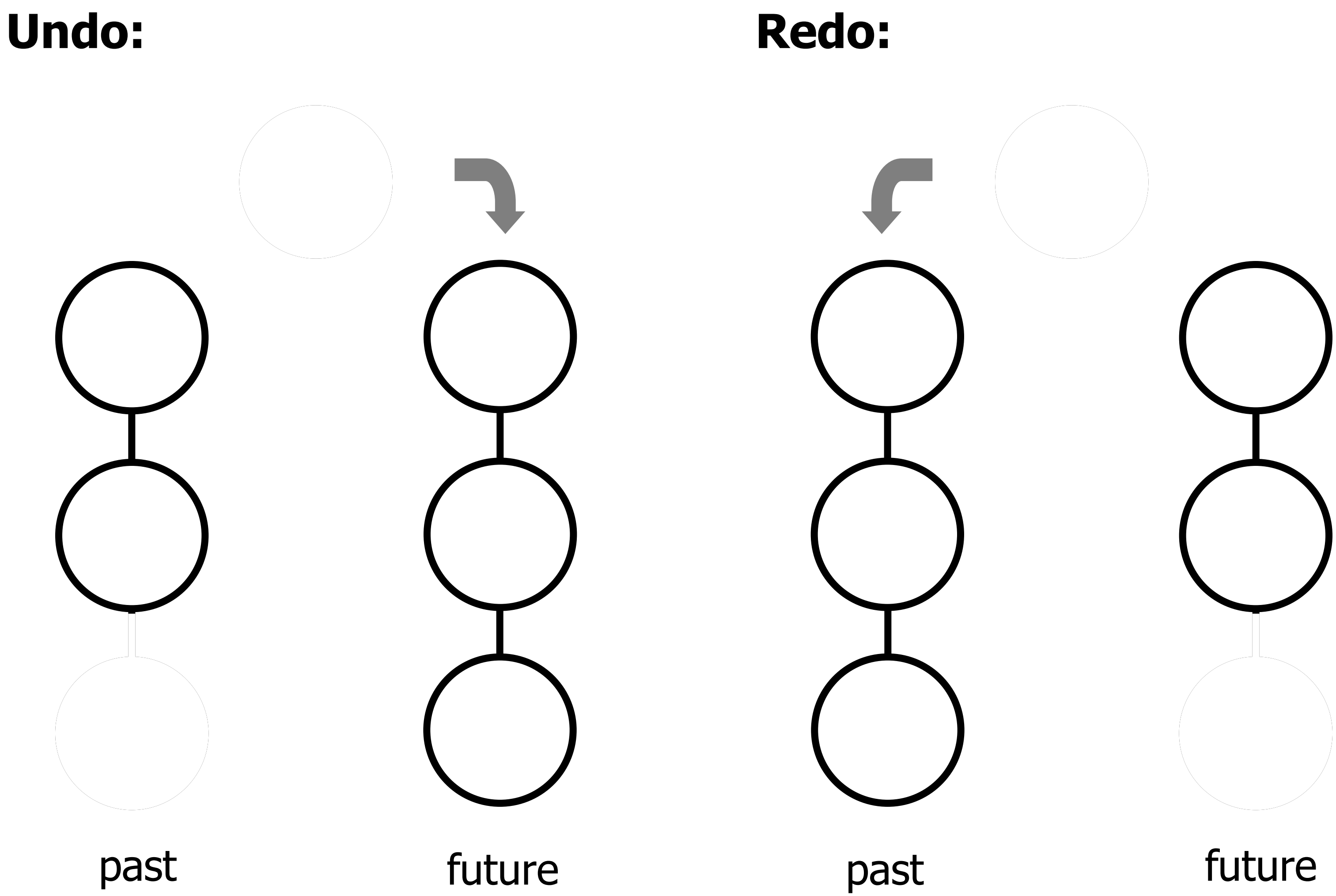
Interface:

```
                      Expression_Tree_Command (Expression_Tree_Command_Impl *=0)
                      Expression_Tree_Command (const Expression_Tree_Command &)
Expression_Tree_Command & operator= (const Expression_Tree_Command &)
                      ~Expression_Tree_Command (void)
                 bool execute (void)
                 bool unexecute (void)
```

Commonality: Provides a common interface for expression tree commands

Variability: The implementations of the expression tree commands can vary depending on the operations requested by user input

List of Commands = Execution History



Command — object behavioral

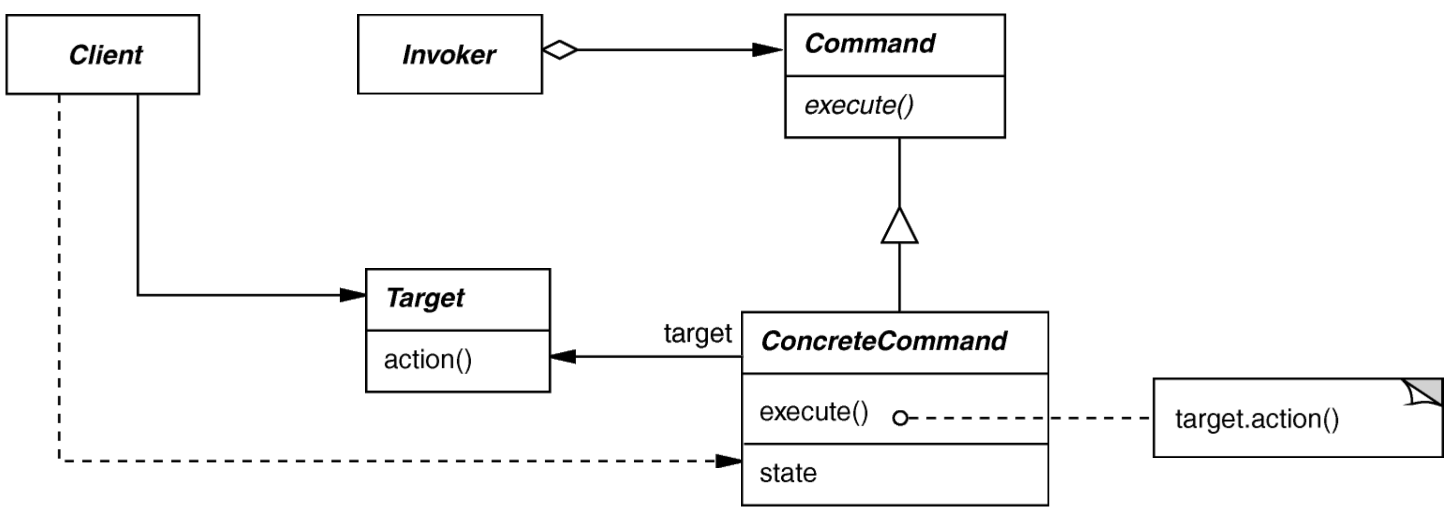
Intent

Encapsulate the request for a service

Applicability

- to parameterize objects with an action to perform
- to specify, queue, & execute requests at different times
- for multilevel undo/redo

Structure



Command object behavioral

Consequences

+ abstracts executor of a service
+ supports arbitrary-level undo-redo
+ composition yields macro-commands
– might result in lots of trivial command subclasses
– excessive memory may be needed to support undo/redo operations

Implementation

- copying a command before putting it on a history list
- handling hysteresis
- supporting transactions

Known Uses

- InterViews Actions
- MacApp, Unidraw Commands
- JDK's UndoableEdit, AccessibleAction
- Emacs
- Microsoft Office tools

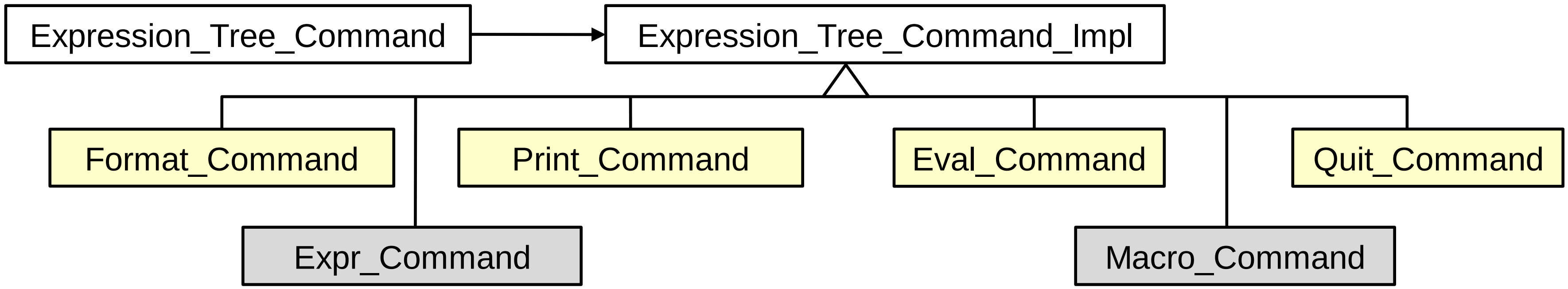
Consolidating Creation of Variabilities

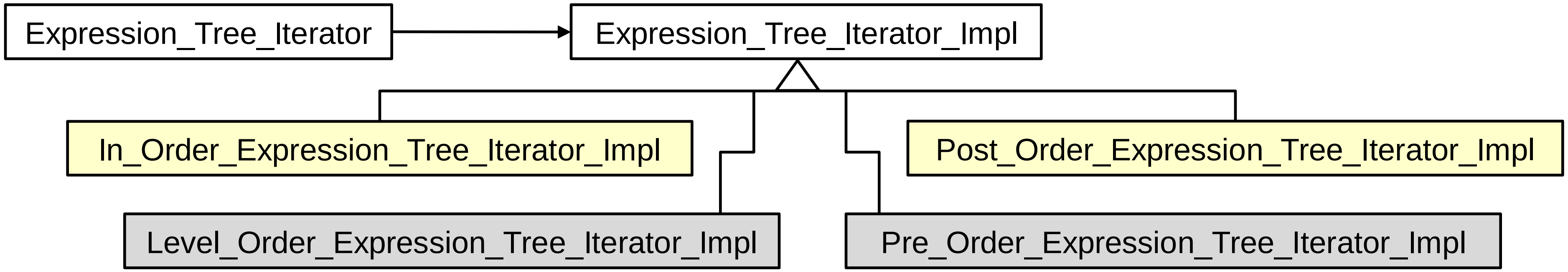
Goals:

- Simplify & centralize the creation of all variabilities in the expression tree application to ensure semantic compatibility
- Be extensible for future variabilities

Constraints/forces:

- Don't recode existing clients
- Add new variabilities without recompiling





Solution: Abstract Object Creation

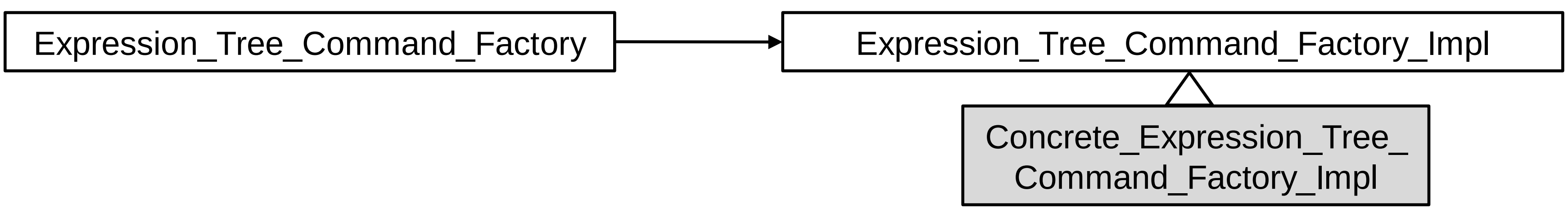
Instead of

```
Expression_Tree_Command command
  = new Print_Command ();
```

Use

```
Expression_Tree_Command command
  = command_factory.make_command ("print");
```

where `command_factory` is an instance of `Expression_Tree_Command_Factory` or anything else that makes sense wrt our goals



Expression_Tree_Command_Factory

Interface for Abstract Factory pattern used to create appropriate command based on string supplied by caller

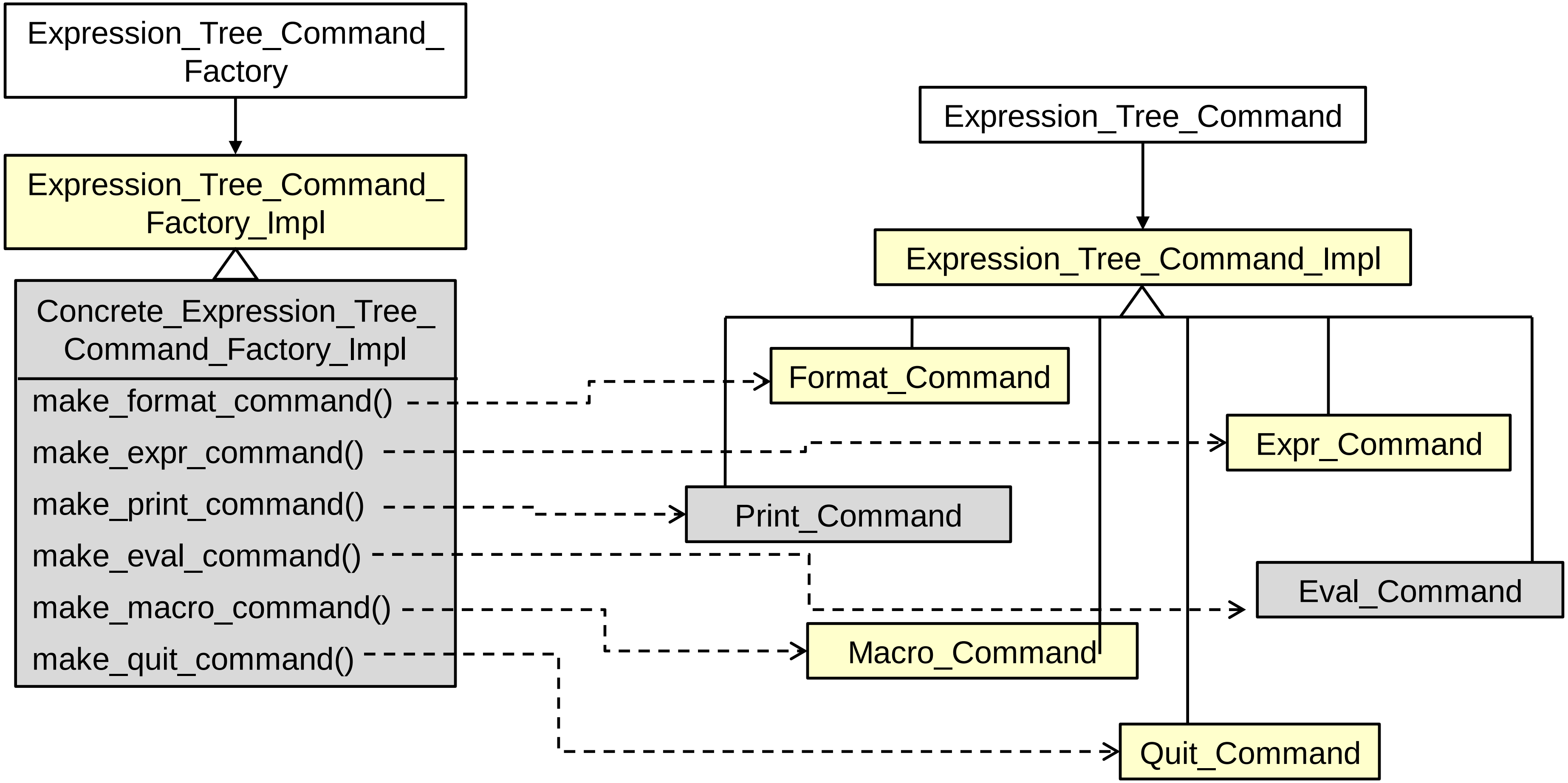
Interface:

```
                                Expression_Tree_Command_Factory
                                            (Expression_Tree_Context &tree_context)
                                Expression_Tree_Command_Factory
                                            (const Expression_Tree_Command_Factory &f)
                           void operator= (const Expression_Tree_Command_Factory &f)
                                ~Expression_Tree_Command_Factory (void)
Expression_Tree_Command make_command (const std::string &s)
Expression_Tree_Command make_format_command (const std::string &)
Expression_Tree_Command make_expr_command (const std::string &)
Expression_Tree_Command make_print_command (const std::string &)
Expression_Tree_Command make_eval_command (const std::string &)
Expression_Tree_Command make_quit_command (const std::string &)
Expression_Tree_Command make_macro_command (const std::string &)
```

Commonality: Provides a common interface to create commands

Variability: The implementations of the expression tree command factory methods can vary depending on the requested commands

Factory Structure



Note use of Bridge pattern to encapsulate variability & simplify memory management

Factory Method class creational

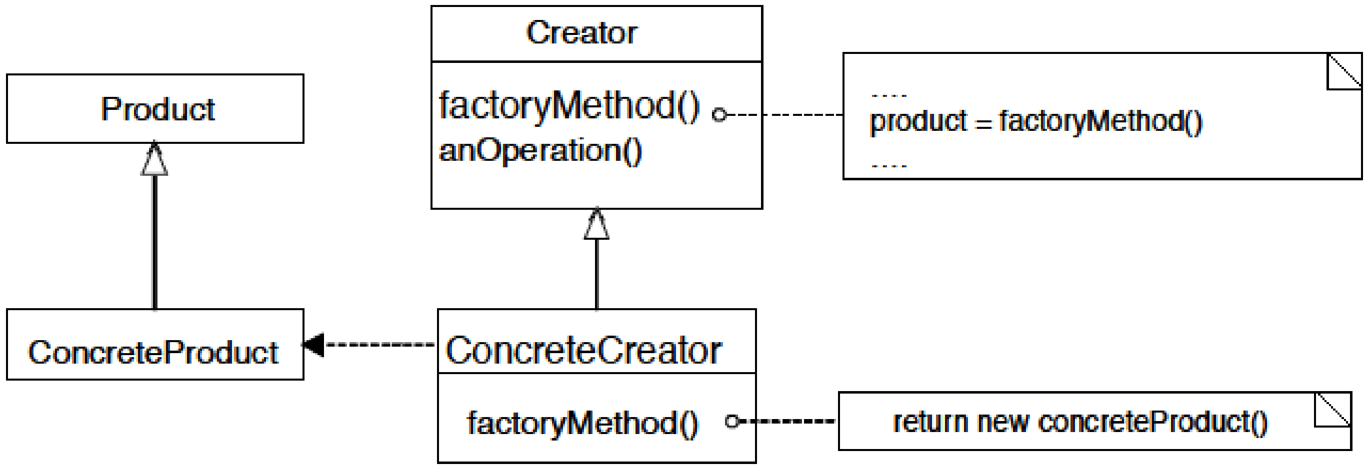
Intent

Provide an interface for creating an object, but leave choice of object's concrete type to a subclass

Applicability

when a class cannot anticipate the objects it must create or a class wants its subclasses to specify the objects it creates

Structure



Factory Method class creational

Consequences

+By avoiding to specify the class name of the concrete class &the details of its creation the client code has become more flexible

+The client is only dependent on the interface

- Construction of objects requires one additional class in some cases

Implementation

- There are two choices here
  - The creator class is abstract & does not implement creation methods (then it *must be subclassed)*
  - The creator class is concrete & provides a default implementation (then it *can be subclassed)*
- Should a factory method be able to create different variants? If so the method must be equipped with a parameter

Known Uses

- InterViews Kits
- ET++ WindowSystem
- AWT Toolkit
- The ACE ORB (TAO)
- BREW
- UNIX open() syscall

Abstract Factory object creational

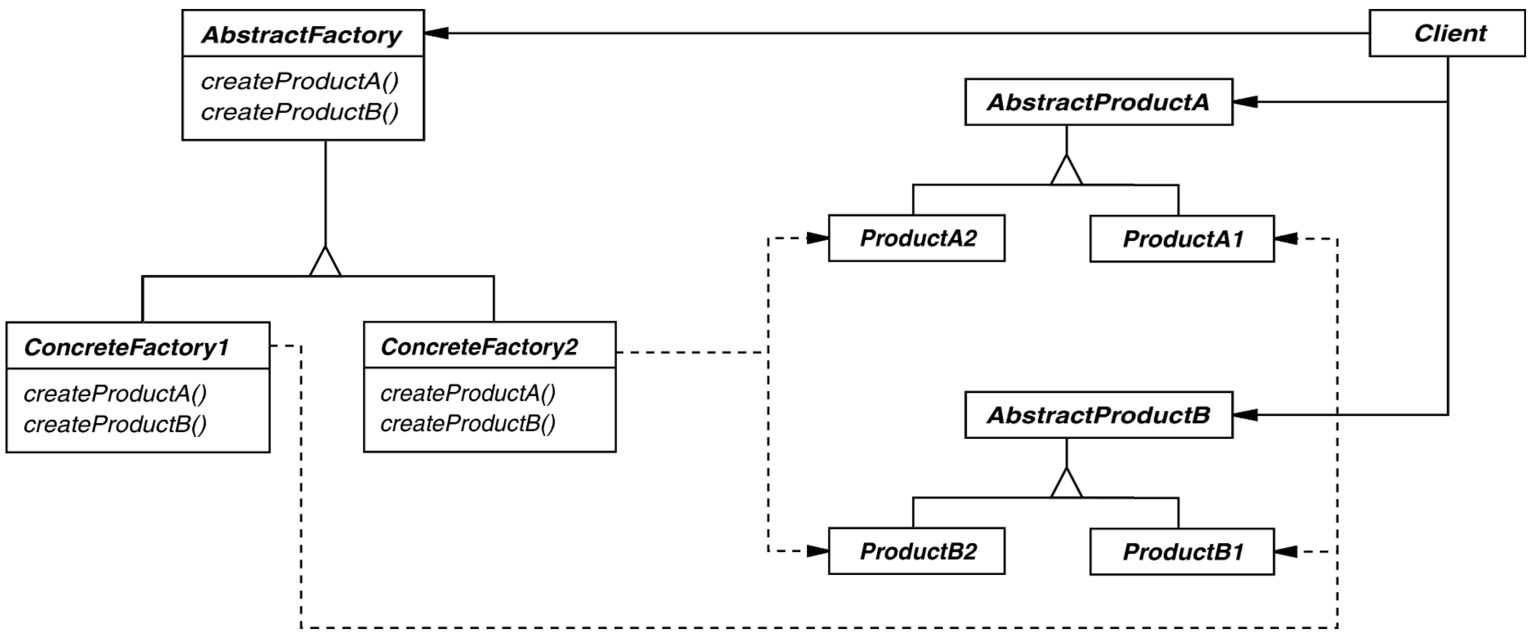
Intent

create families of related objects without specifying subclass names

Applicability

when clients cannot anticipate groups of classes to instantiate

Structure



See `Uninitialized_State_Factory` & `Expression_Tree_Event_Handler` for Factory pattern variants

Abstract Factory — object creational

Consequences

+ flexibility: removes type (i.e., subclass) dependencies from clients
+ abstraction & semantic checking: hides product's composition
– hard to extend factory interface to create new products

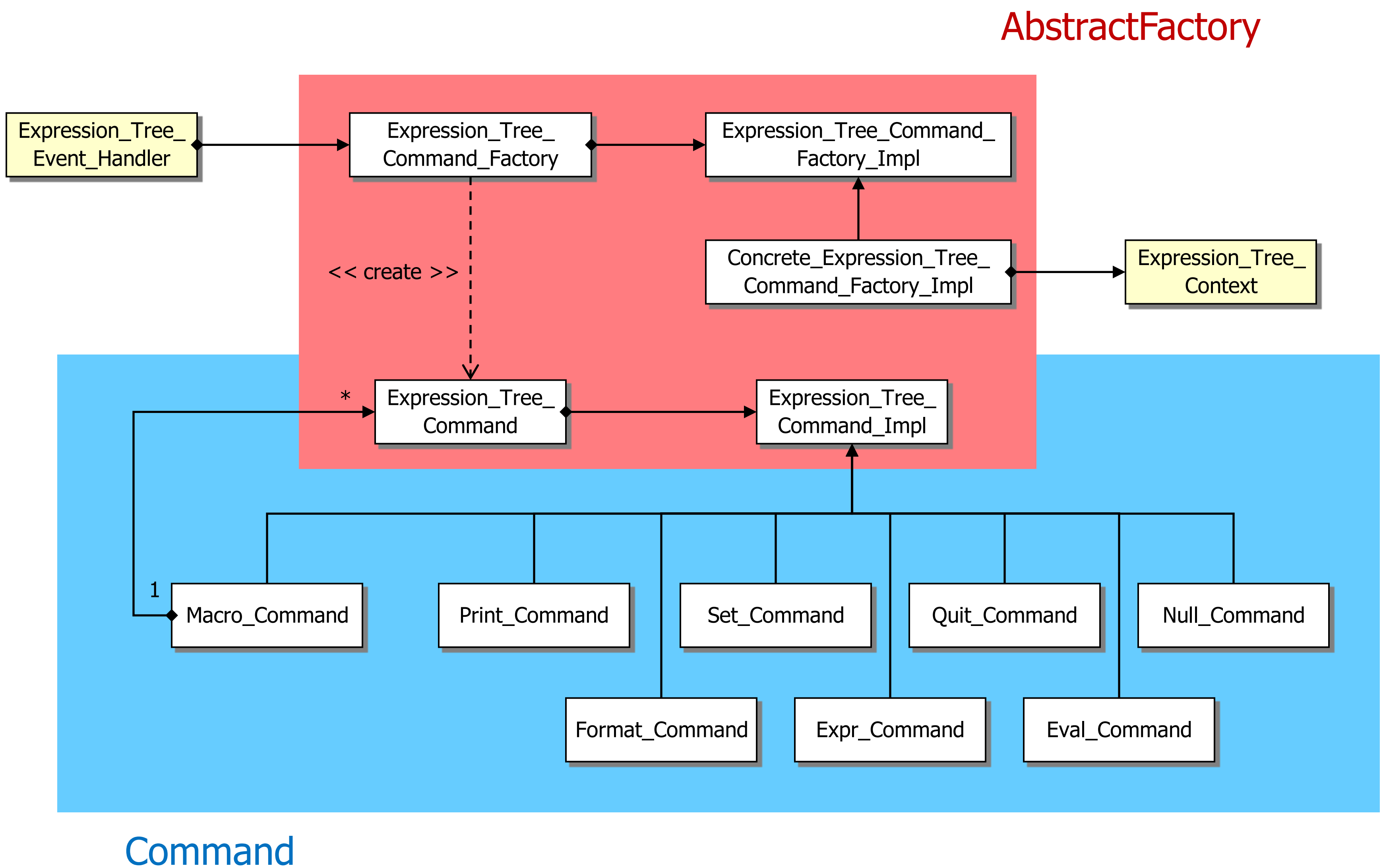
Known Uses

– InterViews Kits
– ET++ WindowSystem
– AWT Toolkit
– The ACE ORB (TAO)

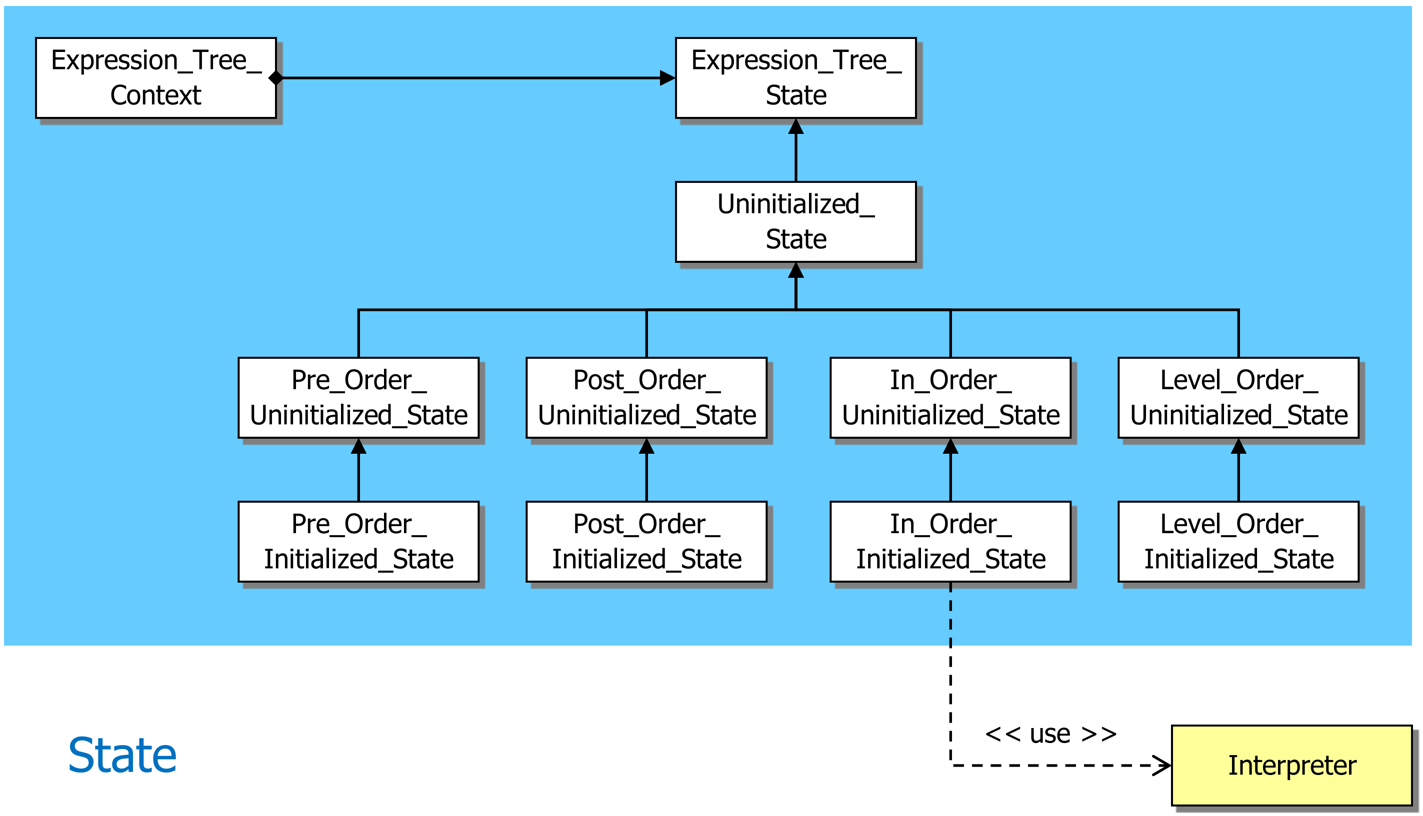
Implementation

- parameterization as a way of controlling interface size
- configuration with Prototypes, i.e., determines who creates the factories
- abstract factories are essentially groups of factory methods

Summary of Command & Factory Patterns



Overview of State Pattern



State

Ensuring Correct Protocol for Commands

Goals:

– Ensure that users follow the correct protocol when entering commands

Constraints/forces:

– Must consider context of previous commands to determine protocol conformance, e.g.,

  – **format** must be called first

  – **expr** must be called before **print** or **eval**

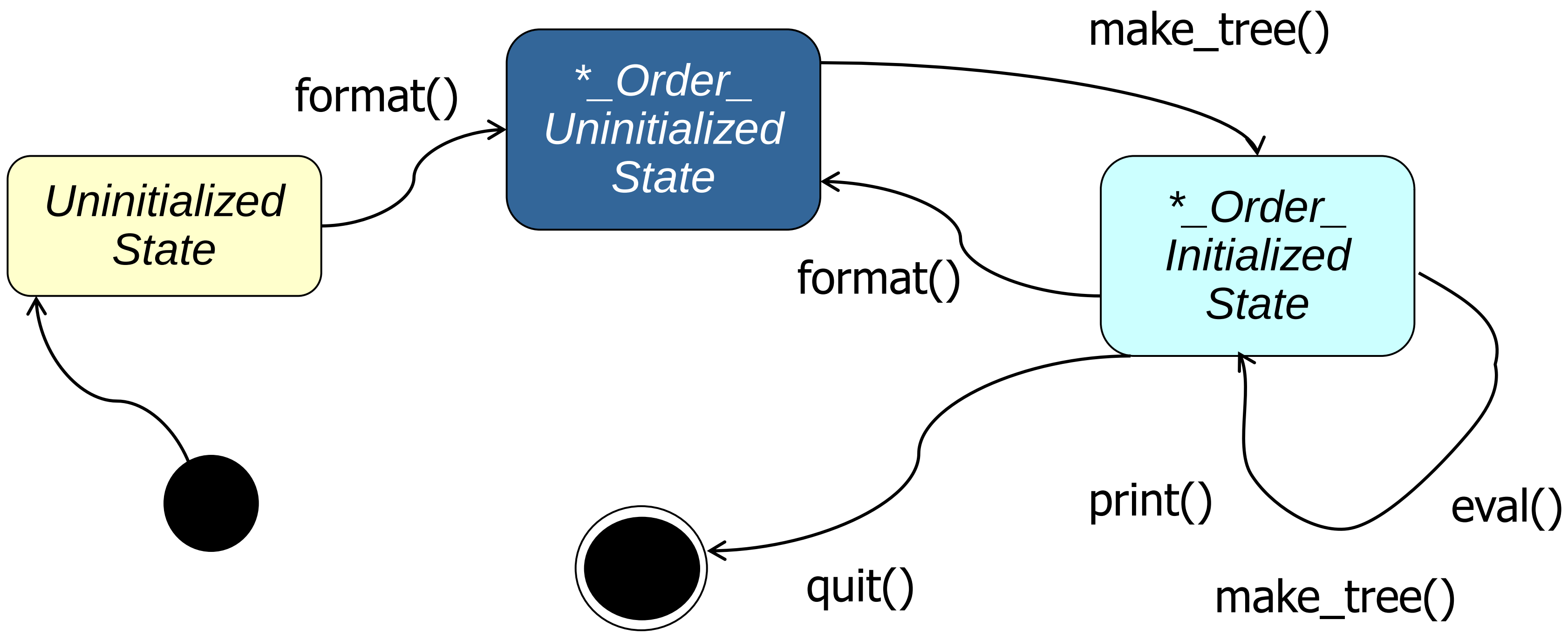
  – **Print** & **eval** can be called in any order

```
% tree-traversal -v
format [in-order]
expr [expression]
print [in-order|pre-order|post-order|level-order]
eval [post-order]
quit
> format in-order
> print in-order
Error: Expression_Tree_State::print called
in invalid state
```

Protocol violation

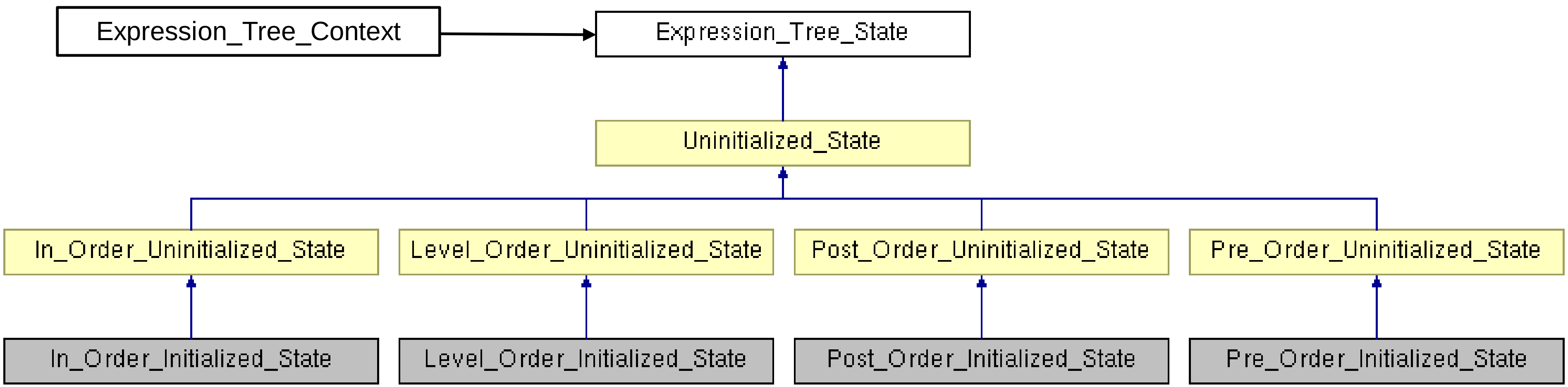
Solution: Encapsulate Command History as States

- The handling of a user command depends on the history of prior commands
- This history can be represented as a state machine



Solution: Encapsulate Command History as States

- The state machine can be encoded using various subclasses that enforce the correct protocol for user commands



Note use of Bridge pattern to encapsulate variability & simplify memory management

Expression_Tree_Context

Interface for State pattern used to ensure that commands are invoked according to the correct protocol

Interface:

```
                   void format (const std::string &new_format)
                   void make_tree (const std::string &expression)
                   void print (const std::string &format)
                   void evaluate (const std::string &format)
Expression_Tree_State * state (void) const
                   void state (Expression_Tree_State *new_state)
      Expression_Tree & tree (void)
                   void tree (const Expression_Tree &new_tree)
```

Commonality: Provides a common interface for ensuring that expression tree commands are invoked according to the correct protocol

Variability: The implementations—& correct functioning—of the expression tree commands can vary depending on the requested operations & the current state

Expression_Tree_State

Implementation of the State pattern that is used to define the various states that affect how users operations are processed

Interface:

```
virtual void format (Expression_Tree_Context &context,
                     const std::string &new_format)
virtual void make_tree (Expression_Tree_Context &context,
                        const std::string &expression)
virtual void print (Expression_Tree_Context &context,
                    const std::string &format)
virtual void evaluate (Expression_Tree_Context &context,
                       const std::string &format)
```

Commonality: Provides a common interface for ensuring that expression tree commands are invoked according to the correct protocol

Variability: The implementations—& correct functioning—of the expression tree commands can vary depending on the requested operations & the current state

State object behavioral

Intent

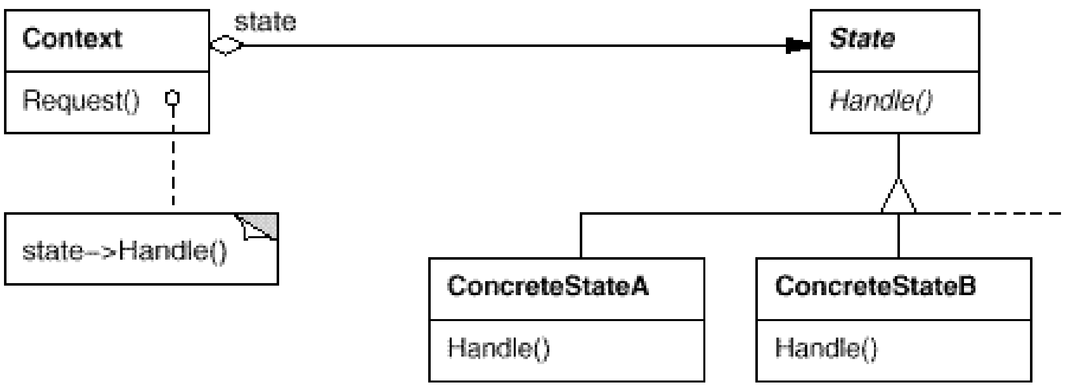
Allow an object to alter its behavior when its internal state changes—the object will appear to change its class

Applicability

– When an object must change its behavior at run-time depending on which state it is in

– When several operations have the same large multipart conditional structure that depends on the object's state

Structure



State object behavioral

Consequences

- \+ It localizes state-specific behavior & partitions behavior for different states
- \+ It makes state transitions explicit
- \+ State objects can be shared
- – Can result in lots of subclasses that are hard to understand

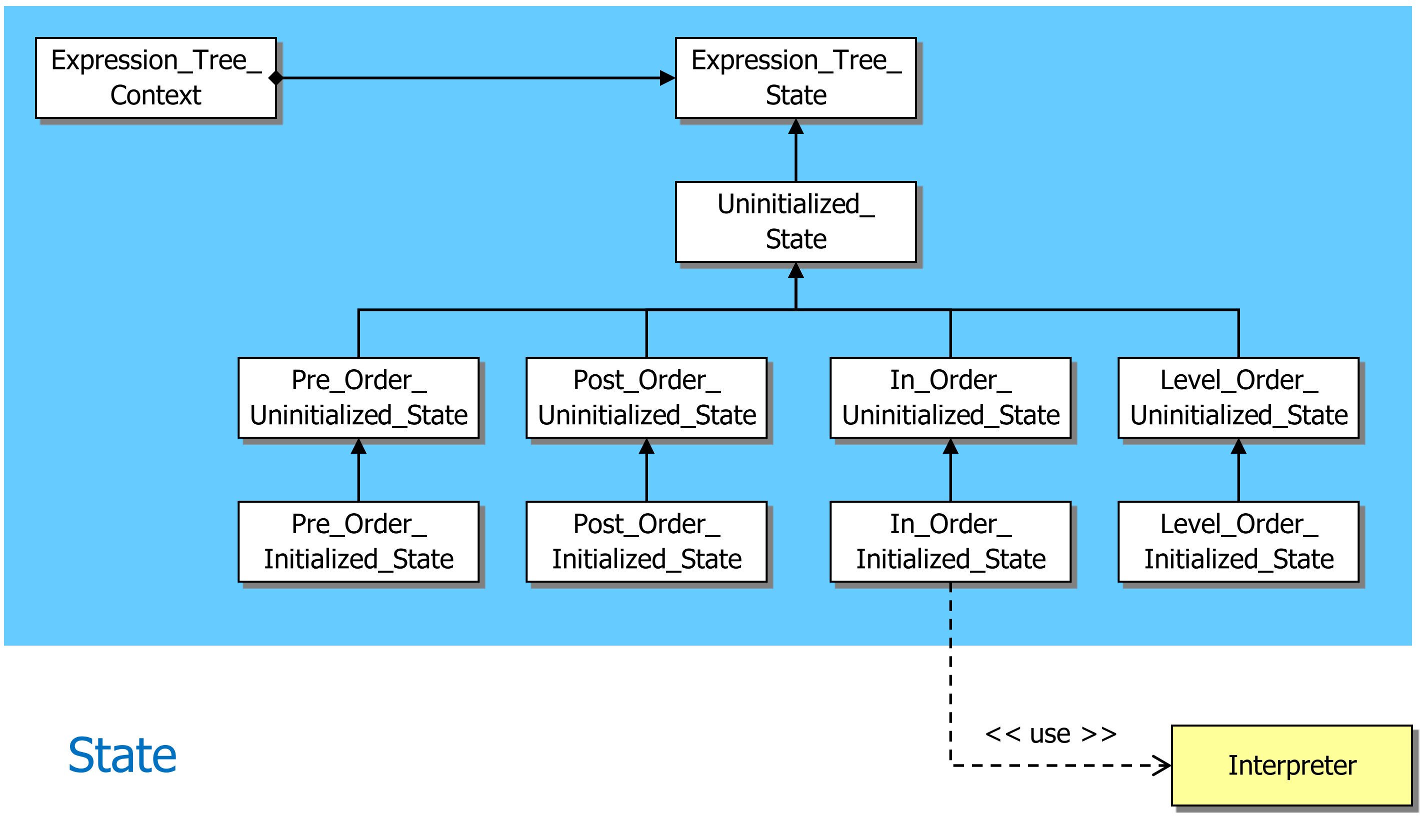
Implementation

- Who defines state transitions?
- Consider using table-based alternatives
- Creating & destroying state objects

Known Uses

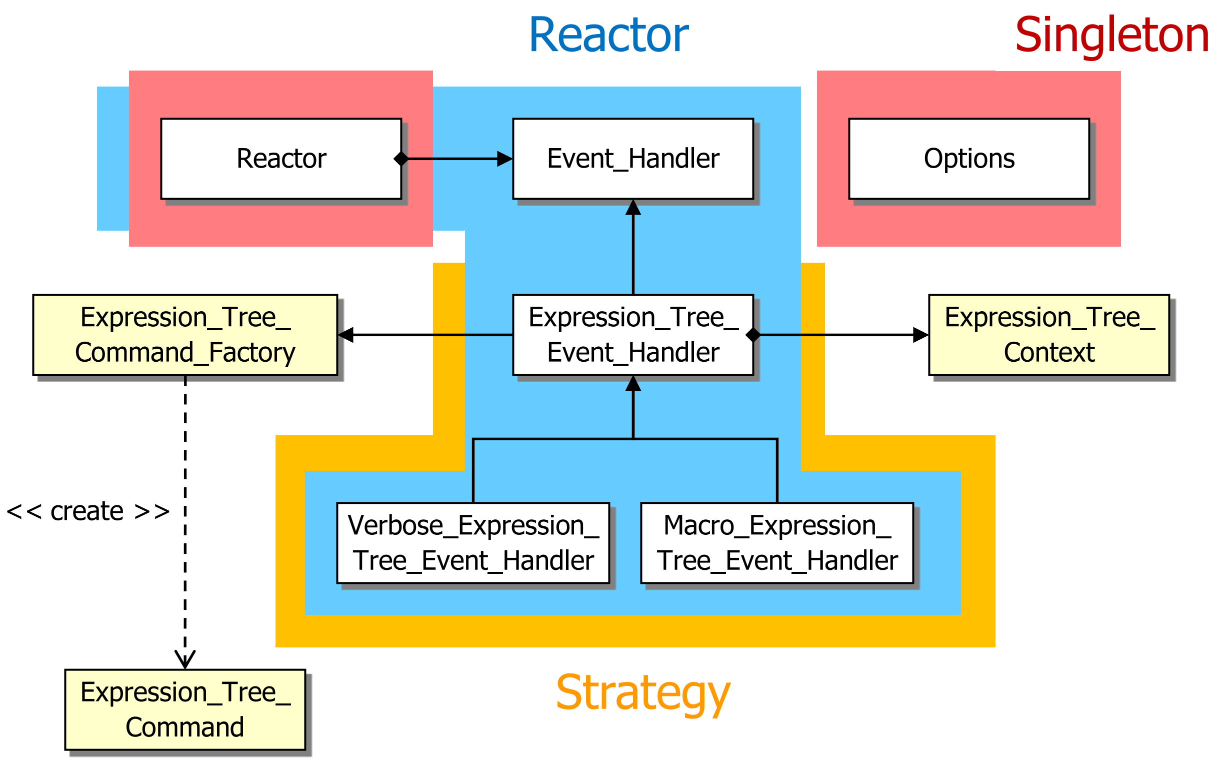
- The State pattern & its application to TCP connection protocols are characterized in: Johnson, R.E. & J. Zweig. "Delegation in C++. Journal of Object-Oriented Programming," 4(11):22-35, November 1991
- Unidraw & Hotdraw drawing tools

Summary of State Pattern



State

Overview of Application Structure Patterns



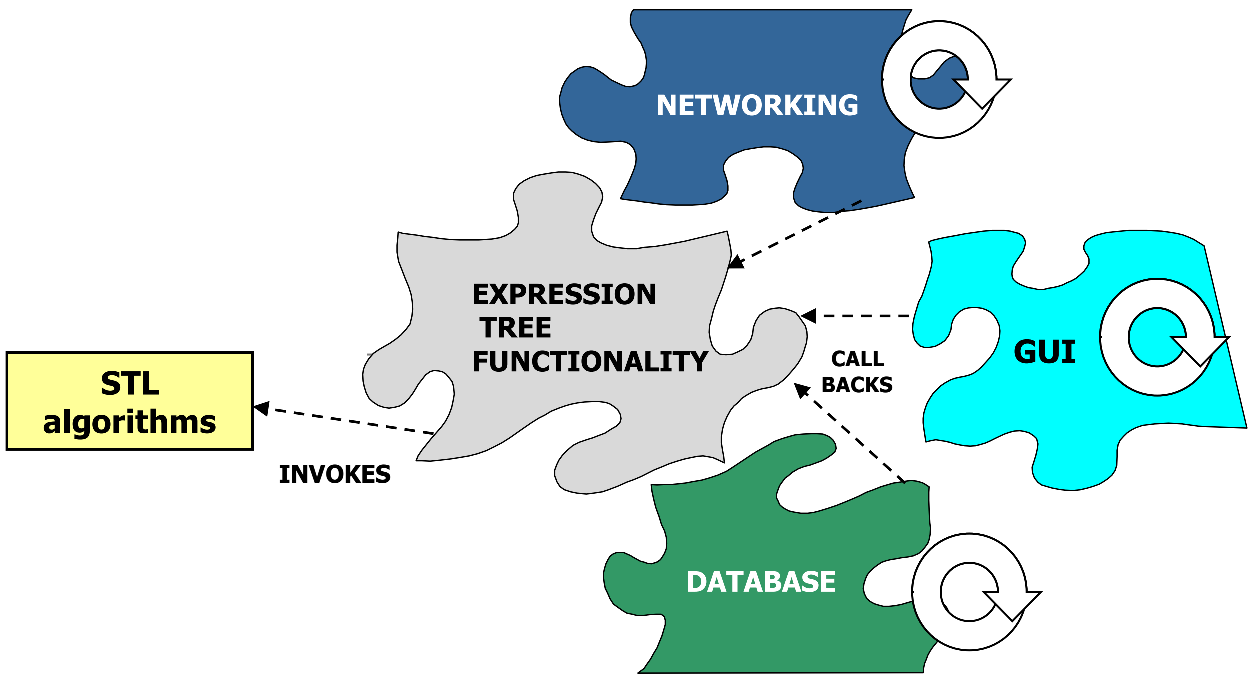
Driving the Application Event Flow

Goals:

- Decouple expression tree application from the context in which it runs
- Support inversion of control

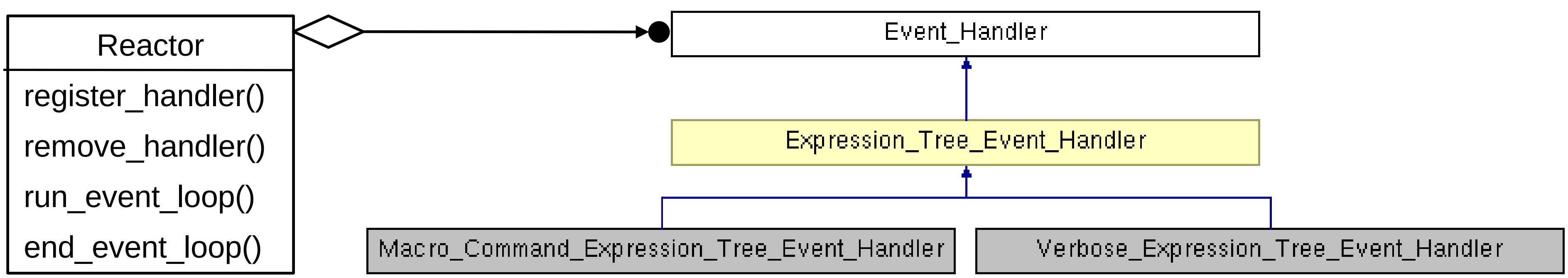
Constraints/forces:

- Don't recode existing clients
- Add new event handles without recompiling



Solution: Separate Event Handling from Event Infrastructure

- Create a reactor to detect input on various sources of events & then demux & dispatch the events to the appropriate event handlers
- Create concrete event handlers that perform the various operational modes of the expression tree application
- Register the concrete event handlers with the reactor
- Run the reactor's event loop to drive the application event flow



Reactor & Event Handler

An object-oriented event demultiplexor & dispatcher of event handler callback methods in response to various types of events

Interface:

virtual void ~Event_Handler (void) =0
virtual void delete_this (void)
virtual void handle_input (void)=0

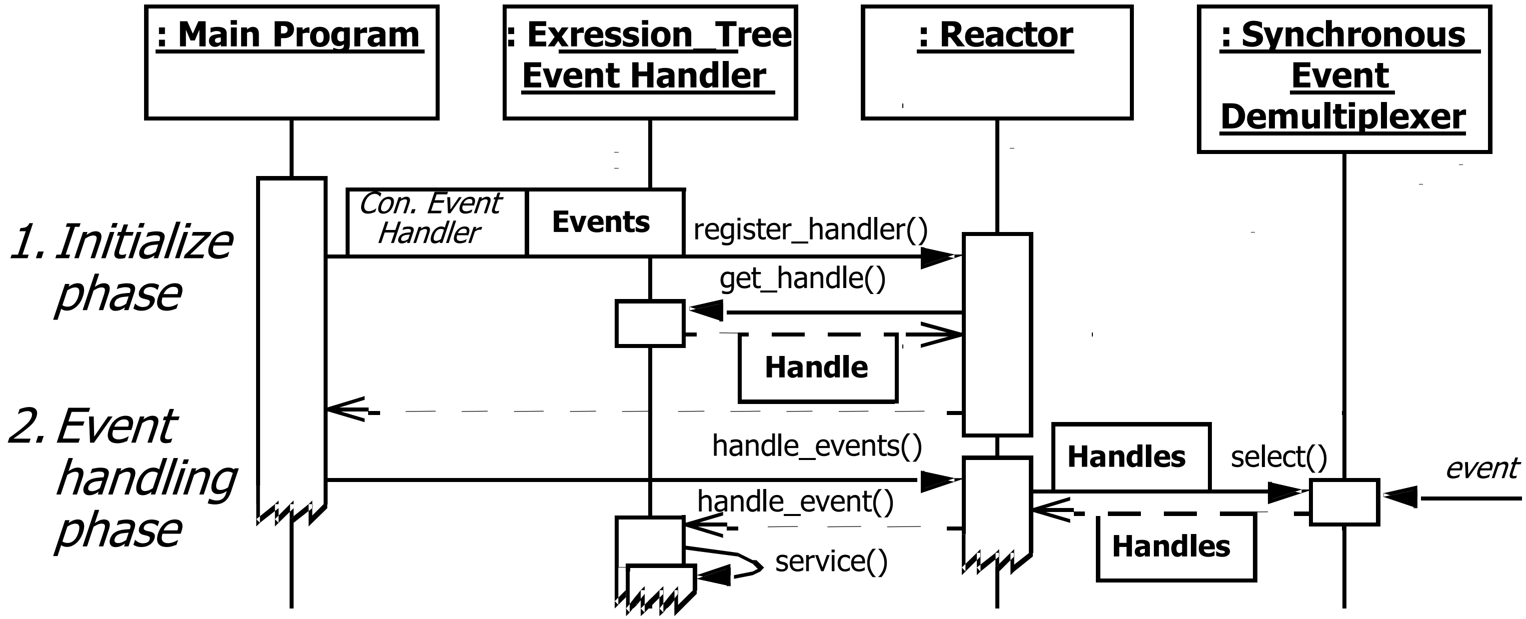
uses

~Reactor (void)
void run_event_loop (void)
void end_event_loop (void)
void register_input_handler (Event_Handler *event_handler)
void remove_input_handler (Event_Handler *event_handler)
static Reactor *instance (void)

Commonality: Provides a common interface for managing & processing events via callbacks to abstract event handlers

Variability: Concrete implementations of the Reactor & Event_Handlers can be tailored to a wide range of OS demuxing mechanisms & application-specific concrete event handling behaviors

Reactor Interactions



Observations

- Note inversion of control
- Also note how long-running event handlers can degrade the QoS since callbacks steal the reactor's thread!

See main.cpp for example of using Reactor to drive event loop

Reactor object behavioral

Intent

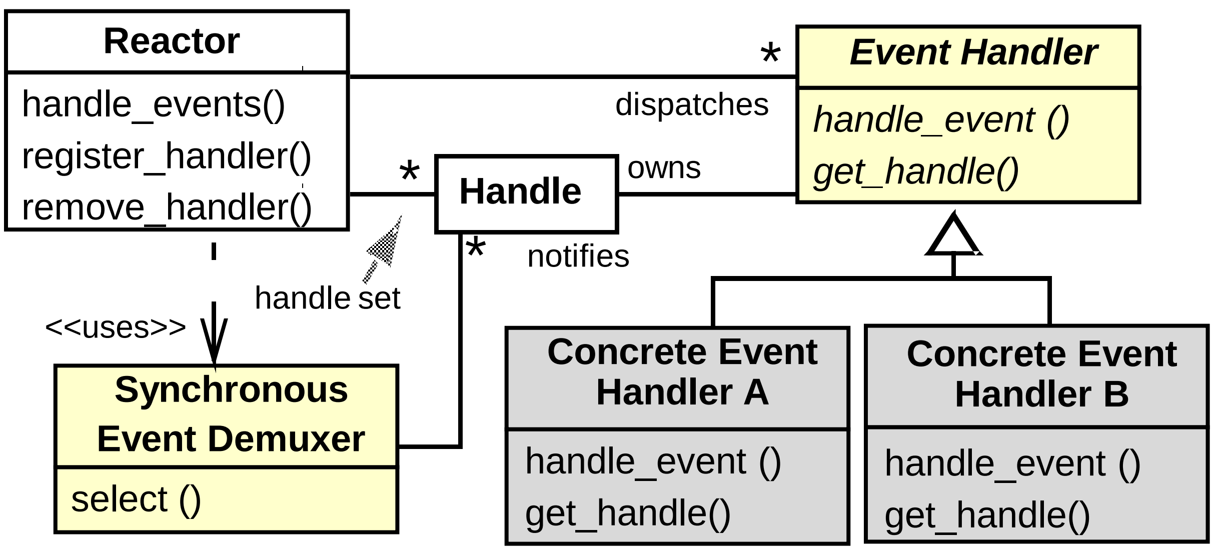
allows event-driven applications to demultiplex & dispatch service requests that are delivered to an application from one or more clients

Applicability

– Need to decouple event handling from event detecting/demuxing/dispatching

– When multiple sources of events must be handled in a single thread

Structure



Reactor object behavioral

Consequences

+ Separation of concerns & portability
+ Simplify concurrency control
– Non-preemptive

Implementation

- Decouple event demuxing mechanisms from event dispatching
- Handle many different types of events, e.g., input/output events, signals, timers, etc.

Known Uses

- InterViews Kits
- ET++ WindowSystem
- AWT Toolkit
- X Windows Xt
- ACE & The ACE ORB (TAO)

Supporting Multiple Operation Modes

Goals:

- Minimize effort required to support multiple modes of operation
  - e.g., verbose & succinct

Constraints/forces:

- support multiple operational modes
- don't tightly couple the operational modes with the program structure to enable future enhancements

Verbose mode

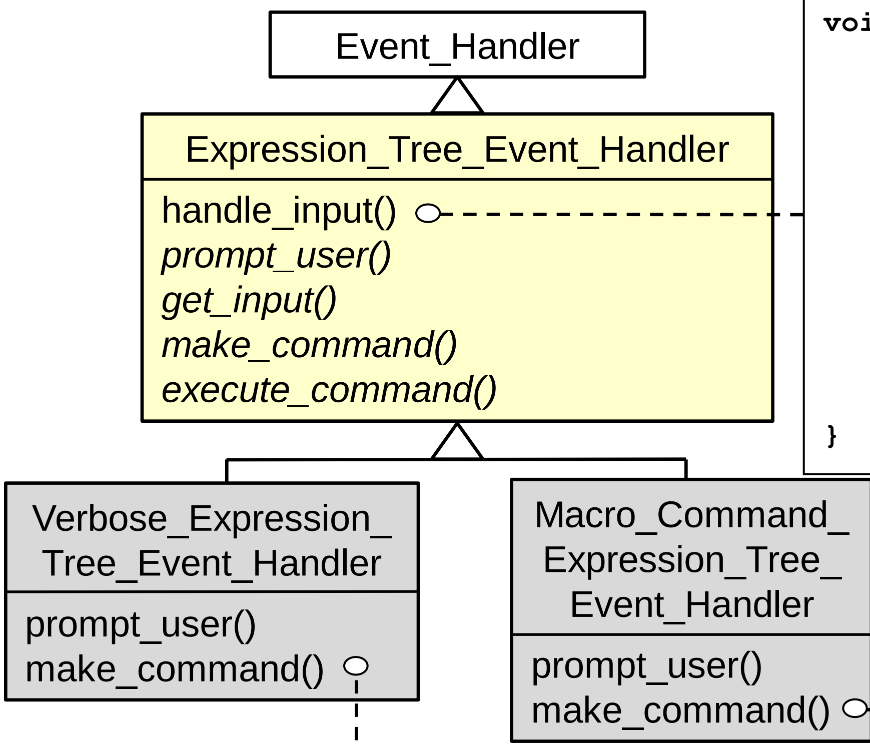
```
% tree-traversal -v
format [in-order]
expr [expression]
print [in-order|pre-order|post-order|level-order]
eval [post-order]
quit
> format in-order
> expr 1+4*3/2
> eval post-order
7
> quit
```

Succinct mode

```
% tree-traversal
> 1+4*3/2
7
```

Solution: Encapsulate Algorithm Variability

Implement algorithm once in base class & let subclasses define variant parts




```
void handle_input (void) { // template method
   prompt_user (); // hook method

   std::string input;

   if (get_input (input) == false) // hook method
     Reactor::instance ()->end_event_loop ();

   Expression_Tree_Command command
     = make_command (input); // hook method

   if (!execute_command (command)) // hook method
     Reactor::instance ()->end_event_loop ();
}
```

```
Expression_Tree_Command make_command
                  (const std::string &input) {
  return
    command_factory_.make_macro_command (input);
}
```

```
Expression_Tree_Command make_command
                  (const std::string  &input) {
  return
     command_factory_.make_command (input);
}
```

Expression_Tree_Event_Handler

Provides an abstract interface for handling input events associated with the expression tree application

Interface:

```
virtual void handle_input (void)
static Expression_Tree_Event_Handler * make_handler (bool verbose)
virtual void prompt_user (void)=0
virtual bool get_input (std::string &)
virtual Expression_Tree_Command make_command
    (const std::string &input)=0
virtual bool execute_command
    (Expression_Tree_Command &)
```

Commonality: Provides a common interface for handling user input events & commands

Variability: Subclasses implement various operational modes, e.g., verbose vs. succinct mode

Note **make_handler()** factory method variant

Template Method class behavioral

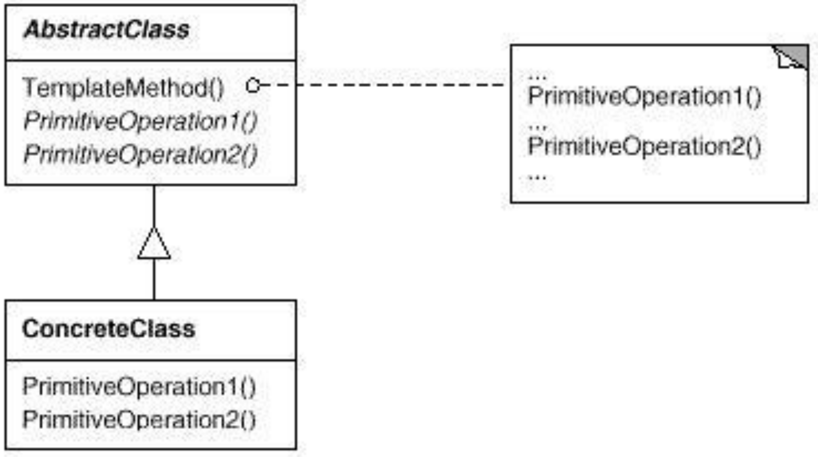
Intent

Provide a skeleton of an algorithm in a method, deferring some steps to subclasses

Applicability

- Implement invariant aspects of an algorithm once & let subclasses define variant parts
- Localize common behavior in a class to increase code reuse
- Control subclass extensions

Structure



Template Method class behavioral

Consequences

+ Leads to inversion of control ("Hollywood principle": don't call us – we'll call you)
+ Promotes code reuse
+ Lets you enforce overriding rules

– Must subclass to specialize behavior (*cf.* Strategy pattern)

Implementation

- Virtual vs. non-virtual template method
- Few vs. lots of primitive operations (hook method)
- Naming conventions (do_*() prefix)

Known Uses

- InterViews Kits
- ET++ WindowSystem
- AWT Toolkit
- ACE & The ACE ORB (TAO)

Strategy object behavioral

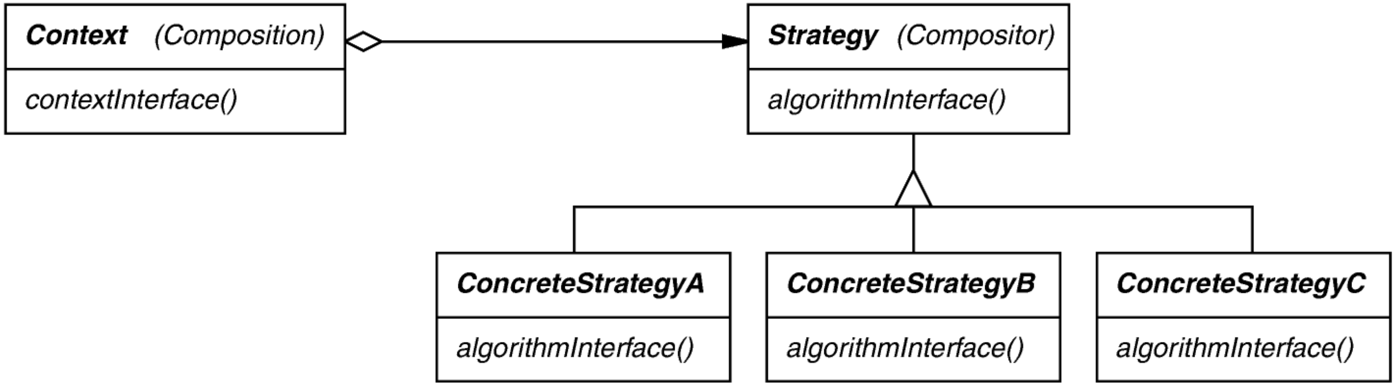
Intent

define a family of algorithms, encapsulate each one, & make them interchangeable to let clients & algorithms vary independently

Applicability

- when an object should be configurable with one of many algorithms,
- *and* all algorithms can be encapsulated,
- *and* one interface covers all encapsulations

Structure



Strategy object behavioral

Consequences

+ greater flexibility, reuse
+ can change algorithms dynamically
– strategy creation & communication overhead
– inflexible Strategy interface
– semantic incompatibility of multiple strategies used together

Implementation

- exchanging information between a Strategy & its context
- static strategy selection via parameterized types

Known Uses

- InterViews text formatting
- RTL register allocation & scheduling strategies
- ET++SwapsManager calculation engines
- The ACE ORB (TAO) Real-time CORBA middleware

See Also

- Bridge pattern (object structural)

Comparing Strategy with Template Method

Strategy

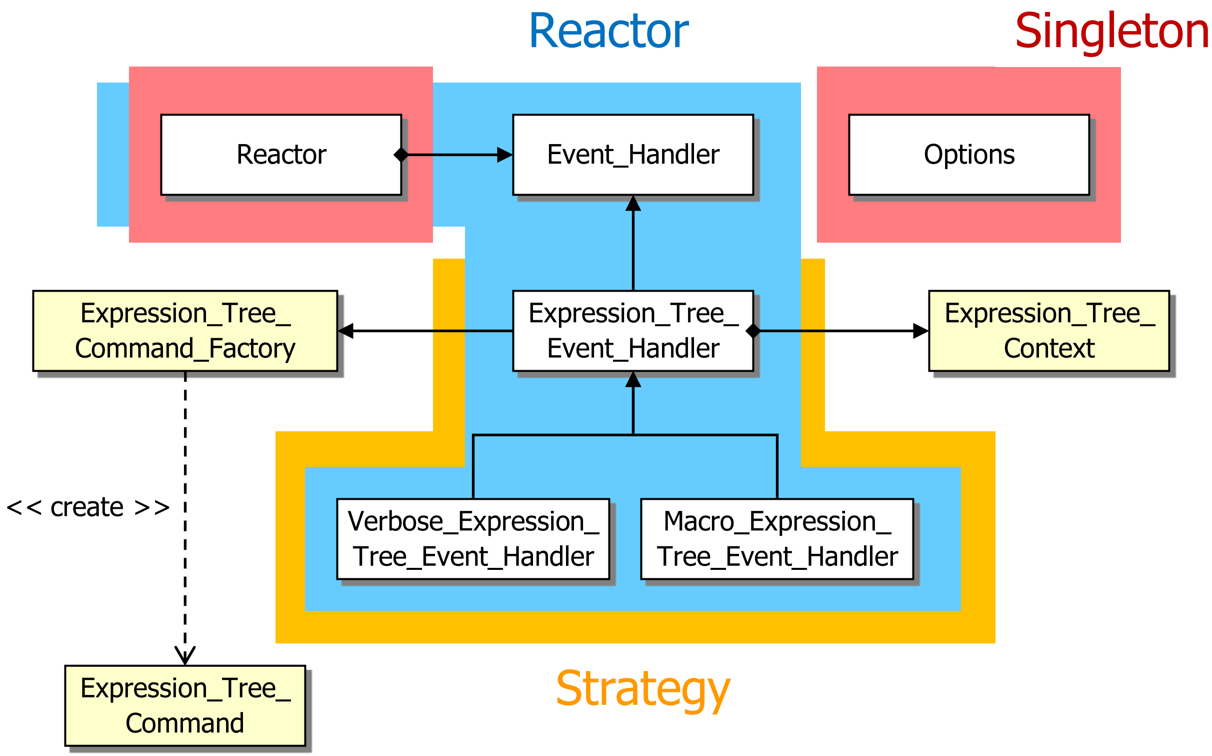
+ Provides for clean separation between components through interfaces
+ Allows for dynamic composition
+ Allows for flexible mixing & matching of features
– Has the overhead of forwarding
– Suffers from the identity crisis
– Leads to more fragmentation

Template Method

+ No explicit forwarding necessary
– Close coupling between subclass(es) & base class
– Inheritance hierarchies are static & cannot be reconfigured at runtime
– Adding features through subclassing may lead to a combinatorial explosion
– Beware of overusing inheritance–inheritance is not always the best choice
– Deep inheritance hierarchy (6 levels & more) in your application is a red flag

Strategy is commonly used for blackbox frameworks
Template Method is commonly used for whitebox frameworks

Summary of Application Structure Patterns



Implementing STL Iterator Semantics

Goals:

– Ensure the proper semantics of post-increment operations for STL-based `Expression_Tree_Iterator` objects

Constraints/forces:

– STL pre-increment operations are easy to implement since they simply increment the value & return *this, e.g.,

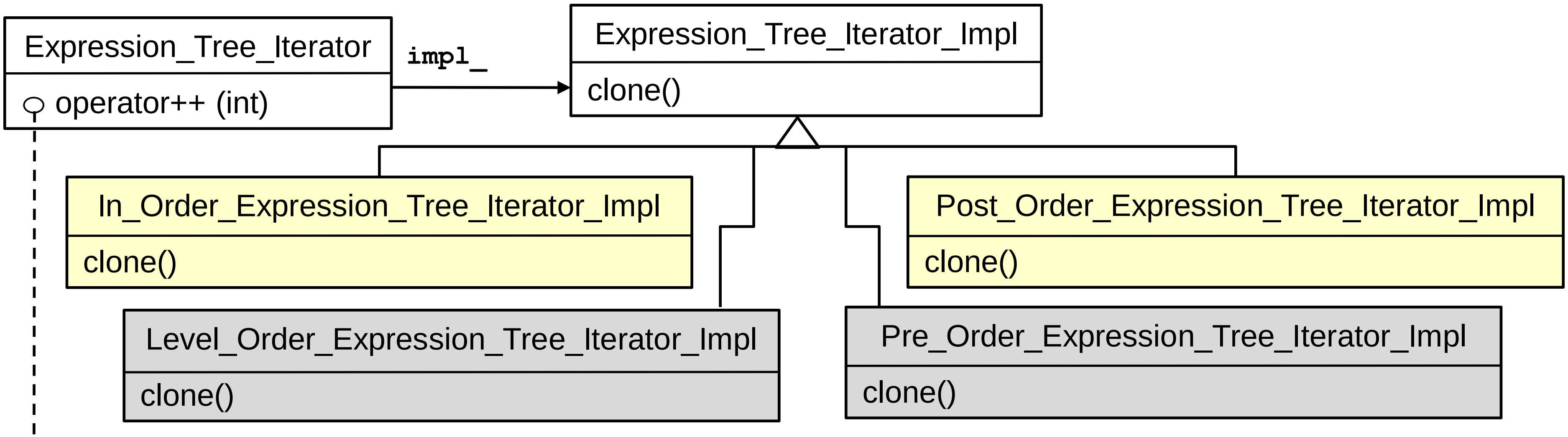
```
iterator &operator++ (void) { ++...; return *this; }
```

– STL post-increment operations are more complicated, however, since must make/return a copy of the existing value of the iterator *before* incrementing its value, e.g.,

```
iterator &operator++ (int) {
  iterator temp = copy_*this; ++...; return temp;
}
```

– Since our `Expression_Tree_Iterator` objects use the Bridge pattern it is tricky to implement the "*copy_*this*" step above in a generic way

Solution: Clone a New Instance From a Prototypical Instance




```
iterator
Expression_Tree_Iterator::operator++ (int)
{
  iterator temp (impl_->clone ());
  ++(*impl_);
  return temp;
}
```

Note use of Bridge pattern to encapsulate variability & simplify memory management

Expression_Tree_Iterator_Impl

Implementation of Iterator pattern used to define various iterations algorithms that can be performed to traverse an expression tree

Interface:

```
Expression_Tree_Iterator_Impl
    (const Expression_Tree &tree)
virtual Component_Node * operator * (void)=0
void operator++ (void)=0
virtual bool operator== (const Expression_Tree_Iterator_Impl &) const=0
virtual bool operator!= (const Expression_Tree_Iterator_Impl &) const=0
virtual Expression_Tree_Iterator_Impl * clone (void)=0
```

Commonality: Provides a common interface for expression tree iterator implementations

Variability: Each subclass implements the `clone()` method to return a deep copy of itself

As a general rule it's better to say ++iter than iter++

Prototype — object creational

Intent

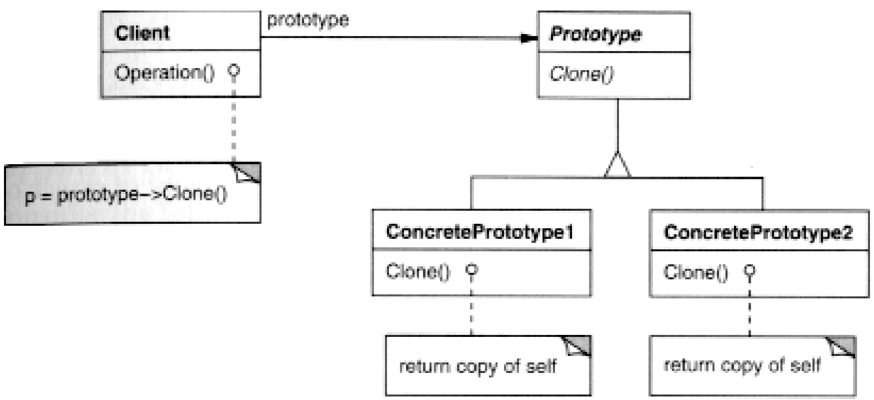
Specify the kinds of objects to create using a prototypical instance & create new objects by copying this prototype

Applicability

– when a system should be independent of how its products are created, composed, & represented

– when the classes to instantiate are specified at run-time; or

Structure



Prototype object creational

Consequences

+ can add & remove classes at runtime by cloning them as needed
+ reduced subclassing minimizes/eliminates need for lexical dependencies at run-time

– every class that used as a prototype must itself be instantiated

– classes that have circular references to other classes cannot really be cloned

Implementation

– Use prototype manager

– Shallow vs. deep copies

– Initializing clone internal state within a uniform interface

Known Uses

– The first widely known application of the Prototype pattern in an object-oriented language was in ThingLab

– Coplien describes idioms related to the Prototype pattern for C++ & gives many examples & variations

– Etgdb debugger for ET++

– The music editor example is based on the Unidraw drawing framework

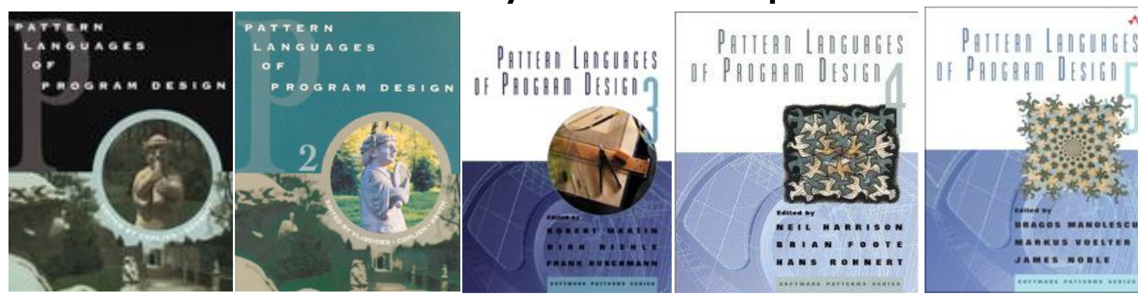
Part III: Wrap-Up

Life Beyond GoF Patterns

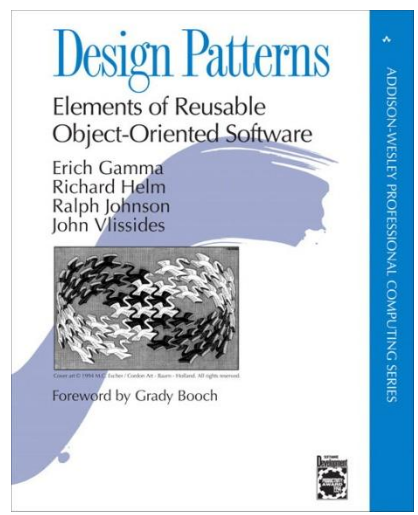
www.cs.wustl.edu/~schmidt/PDF/ieee-patterns.pdf

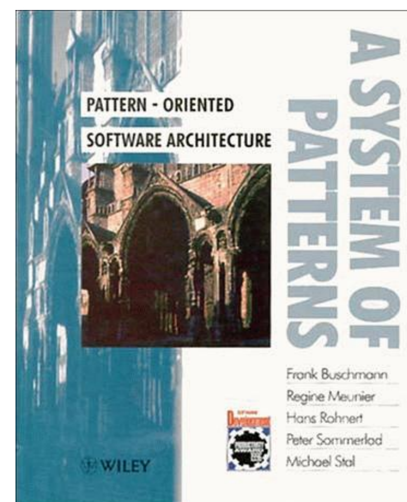
Overview of Pattern Collections

- Stand-alone patterns are point solutions to relatively bounded problems that arise within specific contexts
  - e.g., see the PLoPD books



- Any significant software design inevitably includes many patterns, however, which means that a stand-alone pattern unusual in practice
- A common presentation of multiple patterns is in the form of a *pattern collection*
  - e.g., the GoF & POSA1 books





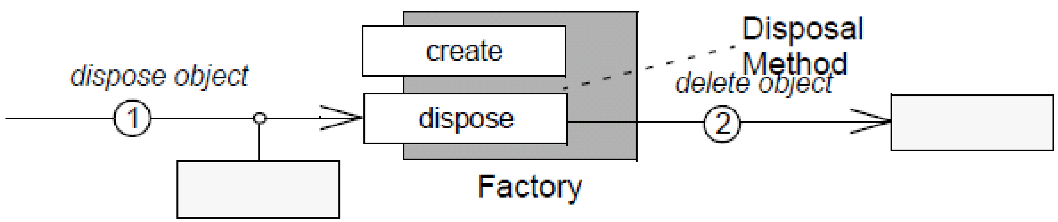
Overview of Pattern Relationships

- Patterns representing the foci for discussion, point solutions, or localized design ideas can be used in isolation with some success
- Patterns are generally gregarious, however, in that they form relationships with other patterns
- Four of the most common types of pattern relationships include:

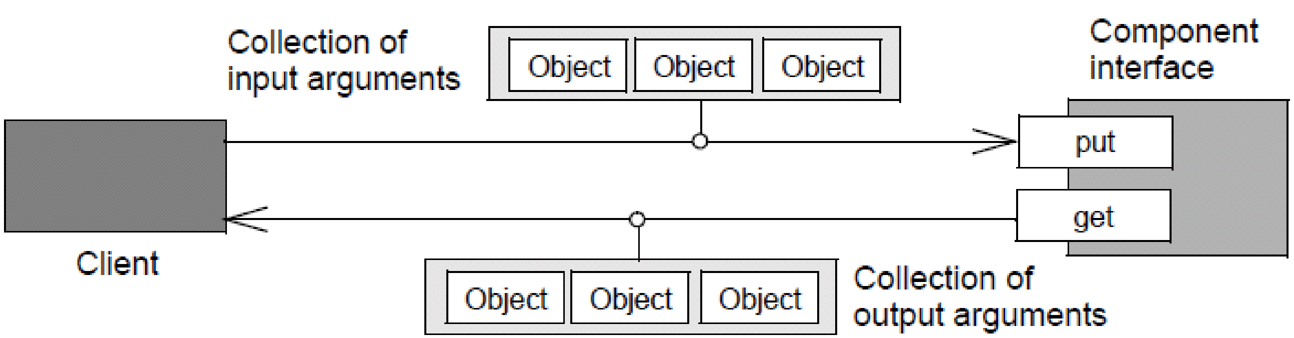
1. ***Patterns complements***, where one pattern provides the missing ingredient needed by another or where one pattern contrasts with another by providing an alternative solution to a related problem
2. ***Pattern compounds*** capture recurring subcommunities of patterns that are common & identifiable enough that they can be treated as a single decision in response to a recurring problem
3. ***Pattern sequences*** generalize the progression of patterns & the way a design can be established by joining predecessor patterns to form part of the context of each successive pattern
4. ***Pattern languages*** define a vocabulary for talking about software development problems & provide a process for the orderly resolution of these problems

Overview of Pattern Complements

- One pattern provides missing ingredient needed by another—or where one pattern competes with another by providing an alternative solution to a related problem—to make resulting designs more complete & balanced, e.g.:
  - *Disposal Method* complements *Factory Method* by addressing object destruction & creation, respectively, in the same design

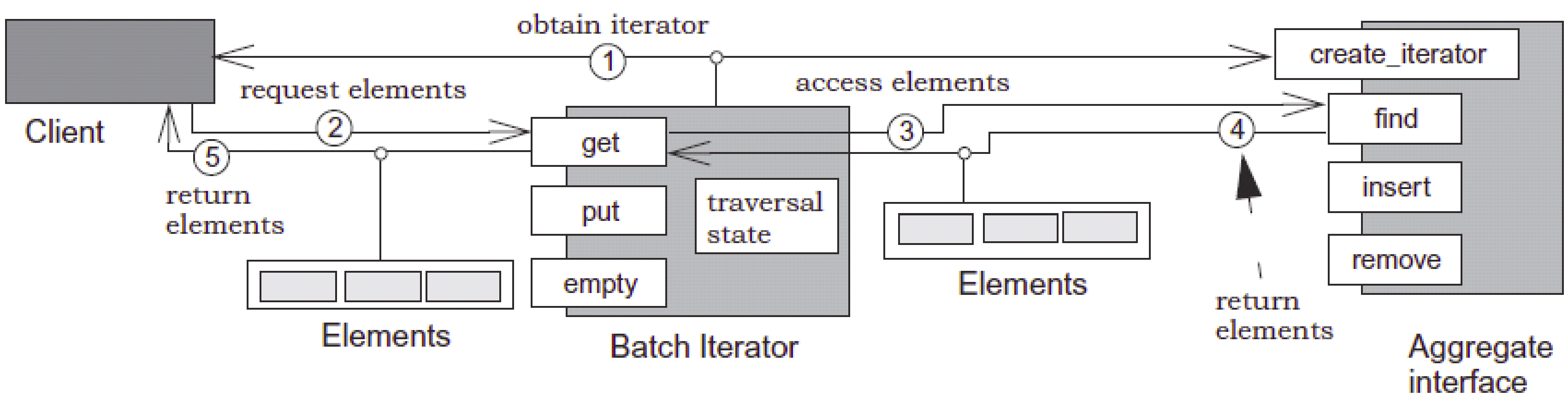


  - *Batch Method* competes with *Iterator* by accessing the elements of an aggregate in bulk, reducing roundtrip network costs



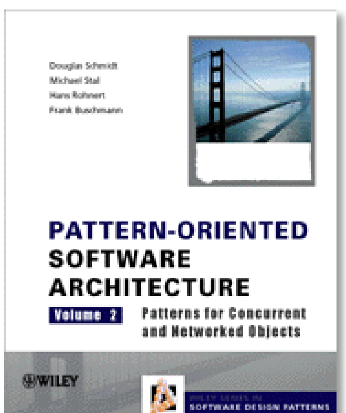
Overview of Pattern Compounds

- Pattern compounds capture recurring subcommunities of patterns that are common & identifiable enough that they can be treated as a single decision in response to a recurring problem
- For example, *Batch Iterator* brings together two complementary patterns, *Iterator* & *Batch Method*, to address the problem of remotely accessing the elements of aggregates with large numbers of elements
- A *Batch Iterator* refines the position-based traversal of an *Iterator* with a *Batch Method* for bulk access of many, but not all, elements



Overview of Pattern Sequences

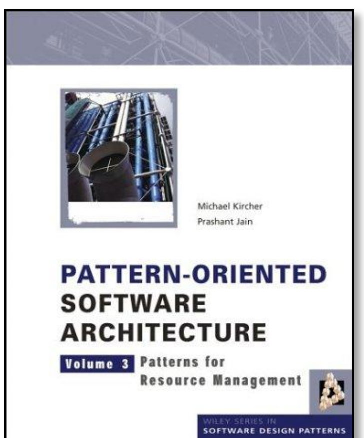
- *Pattern sequences* generalize the progression of patterns & the way a design can be established by joining predecessor patterns to form the context of each successive pattern
- A pattern sequence captures the unfolding of a design or situation, pattern-by-pattern
- e.g., POSA2 & POSA4 present pattern sequences for communication middleware

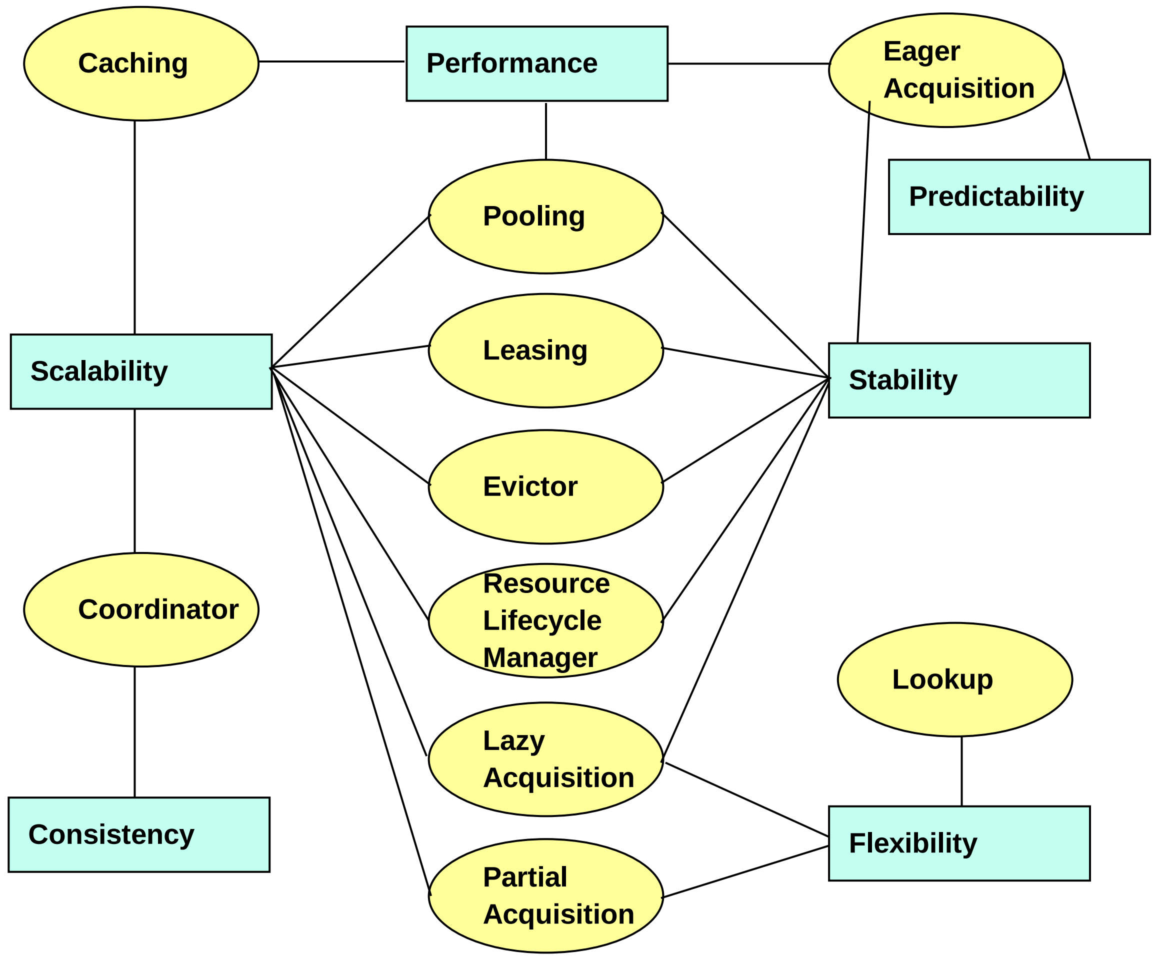


Pattern	Challenges
BROKER	Defining the ORB's base-line architecture
LAYERS	Structuring ORB internal design to enable reuse and clean separation of concerns
WRAPPER FACADE	Encapsulating low-level system functions to enhance portability
REACTOR	Demultiplexing ORB Core events effectively
ACCEPTOR-CONNECTOR	Managing ORB connections effectively
HALF-SYNC/HALF-ASYNC	Enhancing ORB scalability by processing requests concurrently
MONITOR OBJECT	Efficiently synchronize the HALF-SYNC/HALF-ASYNC request queue
STRATEGY	Interchanging internal ORB mechanisms transparently
ABSTRACT FACTORY	Consolidating ORB mechanisms into groups of semantically compatible strategies
COMPONENT CONFIGURATOR	Configuring consolidated ORB strategies dynamically

Overview of Pattern Sequences

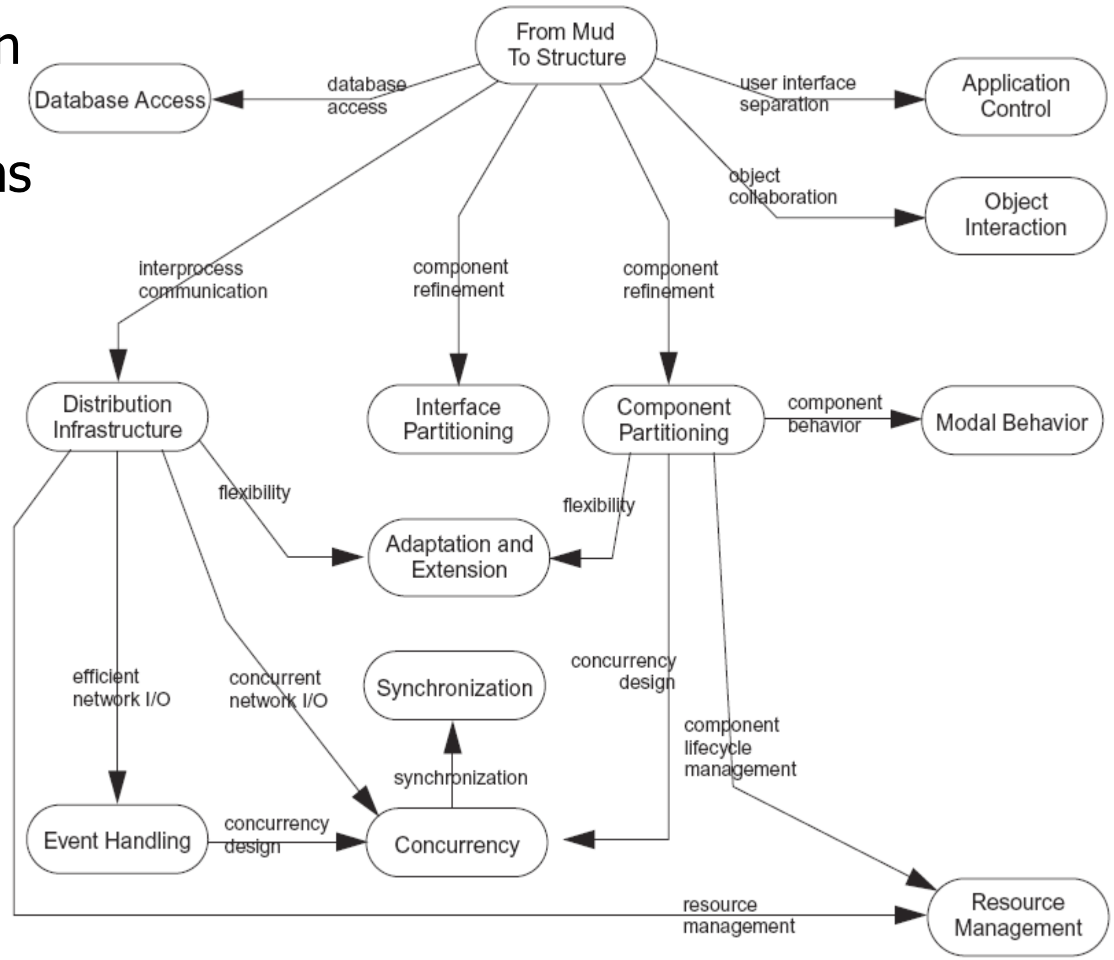
- *Pattern sequences* generalize the progression of patterns & the way a design can be established by joining predecessor patterns to form the context of each successive pattern
- A pattern sequence captures the unfolding of a design or situation, pattern-by-pattern
- e.g., POSA3 presents pattern sequences for resource management

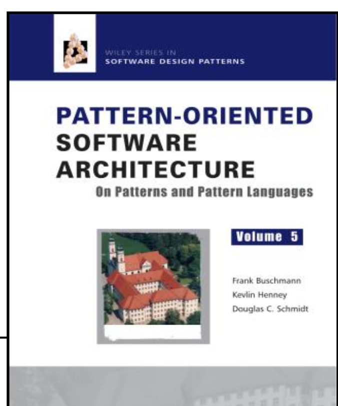




Overview of Pattern Languages

- *Pattern languages* define a vocabulary for talking about software development problems & provide a process for the orderly resolution of these problems
- For example, the POSA4 pattern language for distributed computing includes 114 patterns grouped into 13 problem areas
- Each problem area addresses a specific technical topic related to building distributed systems
- POSA5 describes key concepts of pattern languages





Observations on Applying Patterns & Frameworks

Patterns & frameworks support

- design/implementation at a more abstract level
  - treat many class/object interactions as a unit
  - often beneficial *after* initial design
  - targets for class refactorings
- Variation-oriented design/implementation
  - consider what design aspects are variable
  - identify applicable pattern(s)
  - vary patterns to evaluate tradeoffs
  - repeat

Patterns are applicable in all stages of the OO lifecycle

- analysis, design, & reviews
- realization & documentation
- reuse & refactoring

Patterns often equated with OO languages, but many also apply to C

Caveats to Keep in Mind

Don't apply patterns & frameworks blindly

- Added indirection can yield increased complexity, cost
- Understand patterns to learn how to better develop/use frameworks

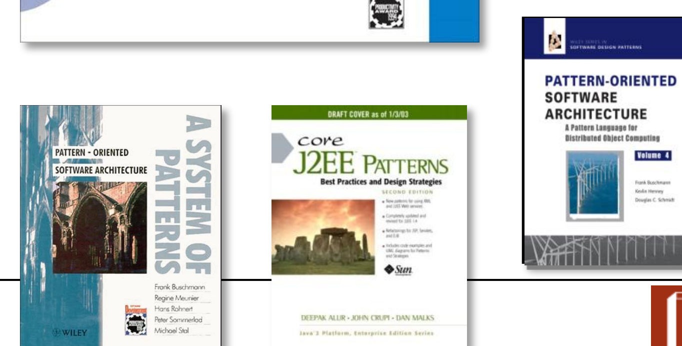
Resist branding everything a pattern

- Articulate specific benefits
- Demonstrate wide applicability
- Find at least *three* existing examples from code other than your own!

Pattern & framework design even harder than OO design!

Concluding Remarks

- Patterns & frameworks promote
  - *Integrated* design & implementation reuse
  - uniform design vocabulary
  - understanding, restructuring, & team communication
  - a basis for automation
  - a "new" way to think about software design & implementation



There's much more to patterns than just the GoF, however!!!!

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How to Study Patterns

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Pattern-Oriented Conferences

PLoP 2010: Pattern Languages of Programs
October 2009, Collocated with OOPSLA

EuroPLoP 2010, July 2010, Kloster Irsee, Germany

...

See hillside.net/conferences/ for
up-to-the-minute info

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ui-patterns@cs.uiuc.edu: discussion on user interface patterns

business-patterns@cs.uiuc.edu: discussion on patterns for business processes

ipc-patterns@cs.uiuc.edu: discussion on patterns for distributed systems

See http://hillside.net/patterns/mailing.htm for an up-to-date list.