A Case Study of "Gang of Four" (GoF) Patterns : Part 10

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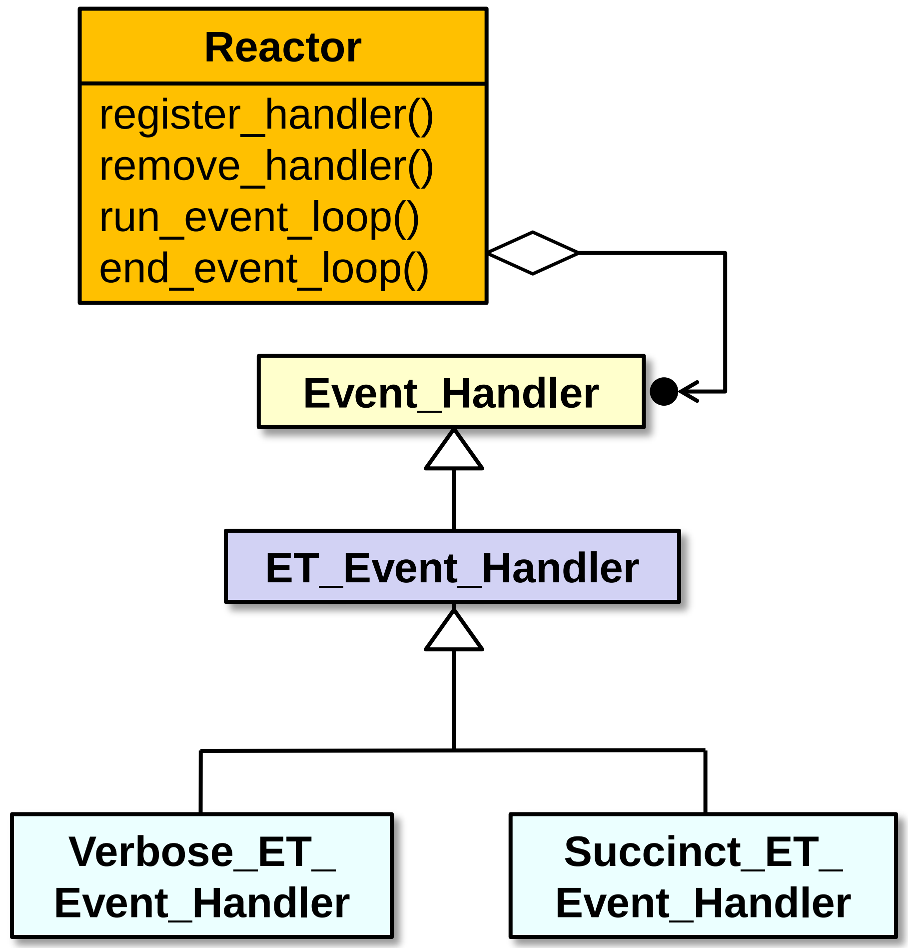
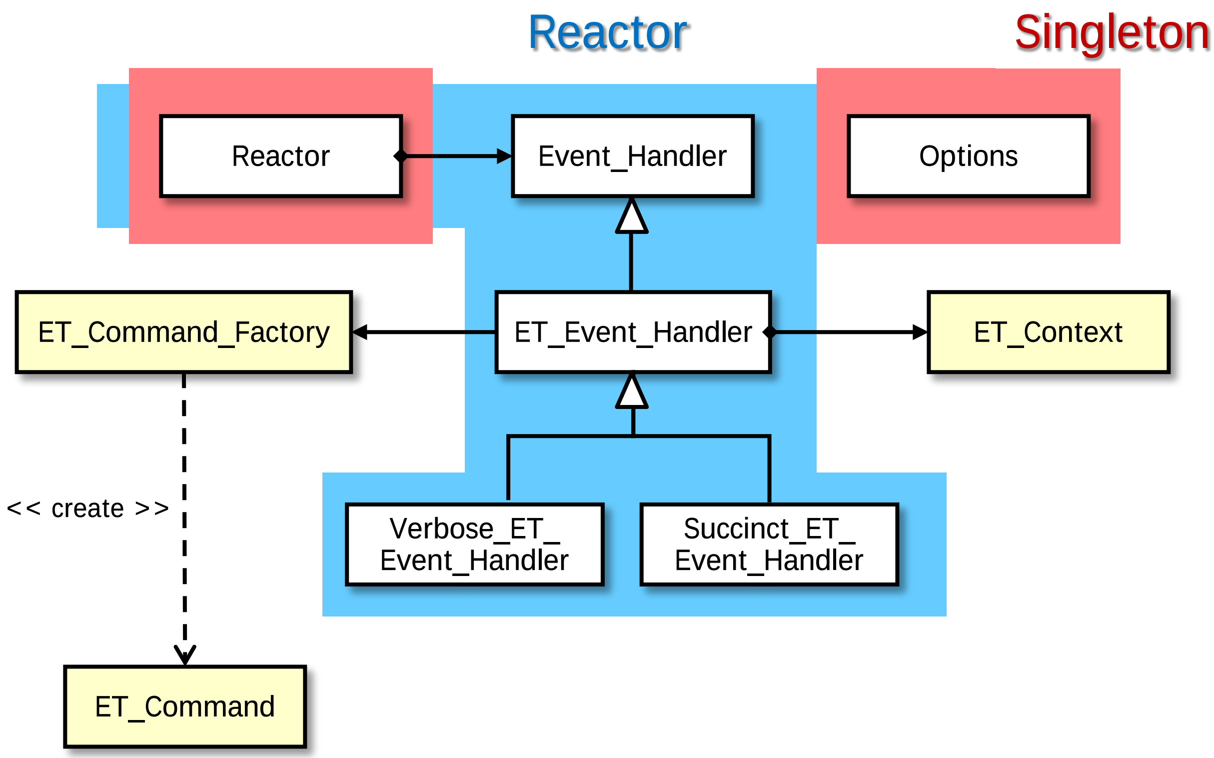
Topics Covered in this Part of the Module

- Describe the object-oriented (OO) expression tree case study
- Evaluate the limitations with algorithmic design techniques
- Present an OO design for the expression tree processing app
- Summarize the patterns in the expression tree design
- Explore patterns for
  - Tree structure & access
  - Tree creation
  - Tree traversal
  - Commands & factories
  - Command ordering protocols
  - Application structure



Overview of Application Structure Patterns

***Purpose**: Structure the overall control flow of the event-driven expression tree processing app*



These patterns simplify processing of events & user options

Problem: Structuring Application Event Flow

Goals

- Decouple expression tree processing app from the context in which it runs
  - e.g., command-line vs. various GUI environments


```
% 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
```

Problem: Structuring Application Event Flow

Goals

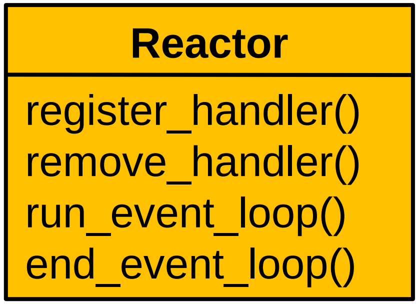
- Decouple expression tree processing app from the context in which it runs
  - e.g., command-line vs. various GUI environments

Constraints / forces

- Don't hard-code control flow into app logic
- Don't hard-code event processing logic into app structure

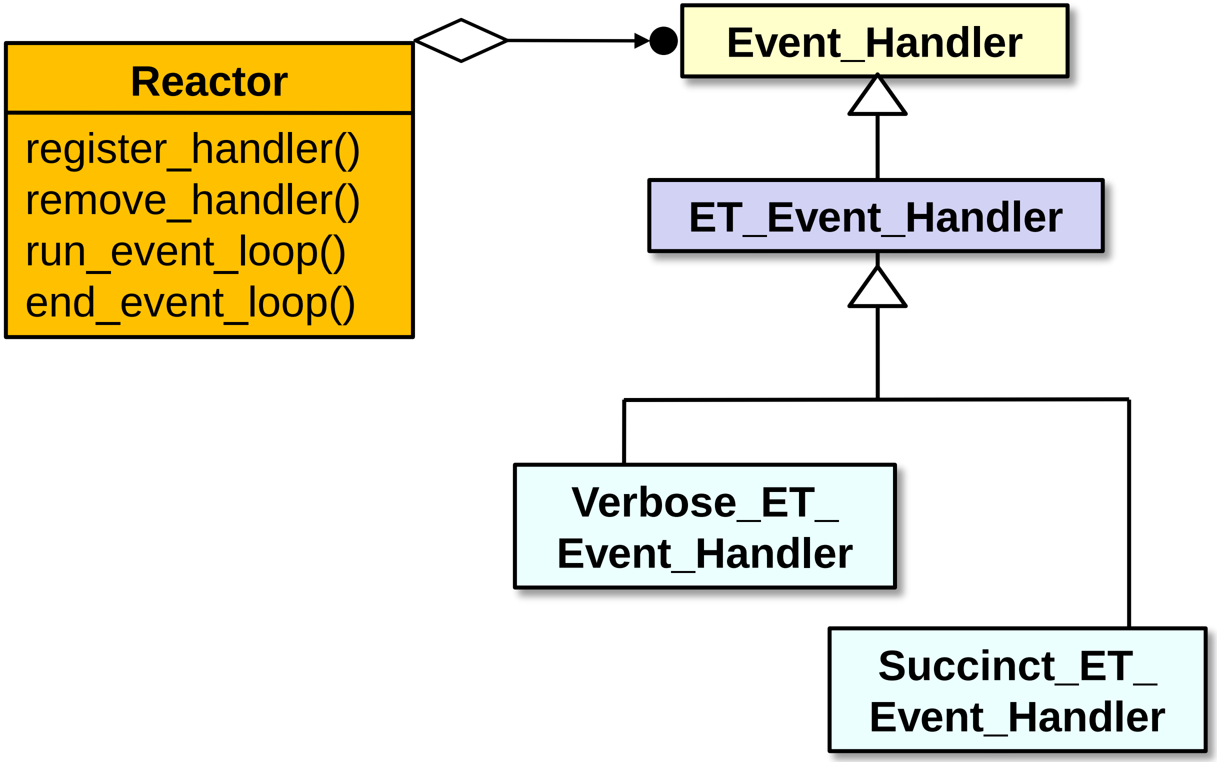
Solution: Separate Event Handling Concerns

- Create a reactor to *detect* input on various sources of events



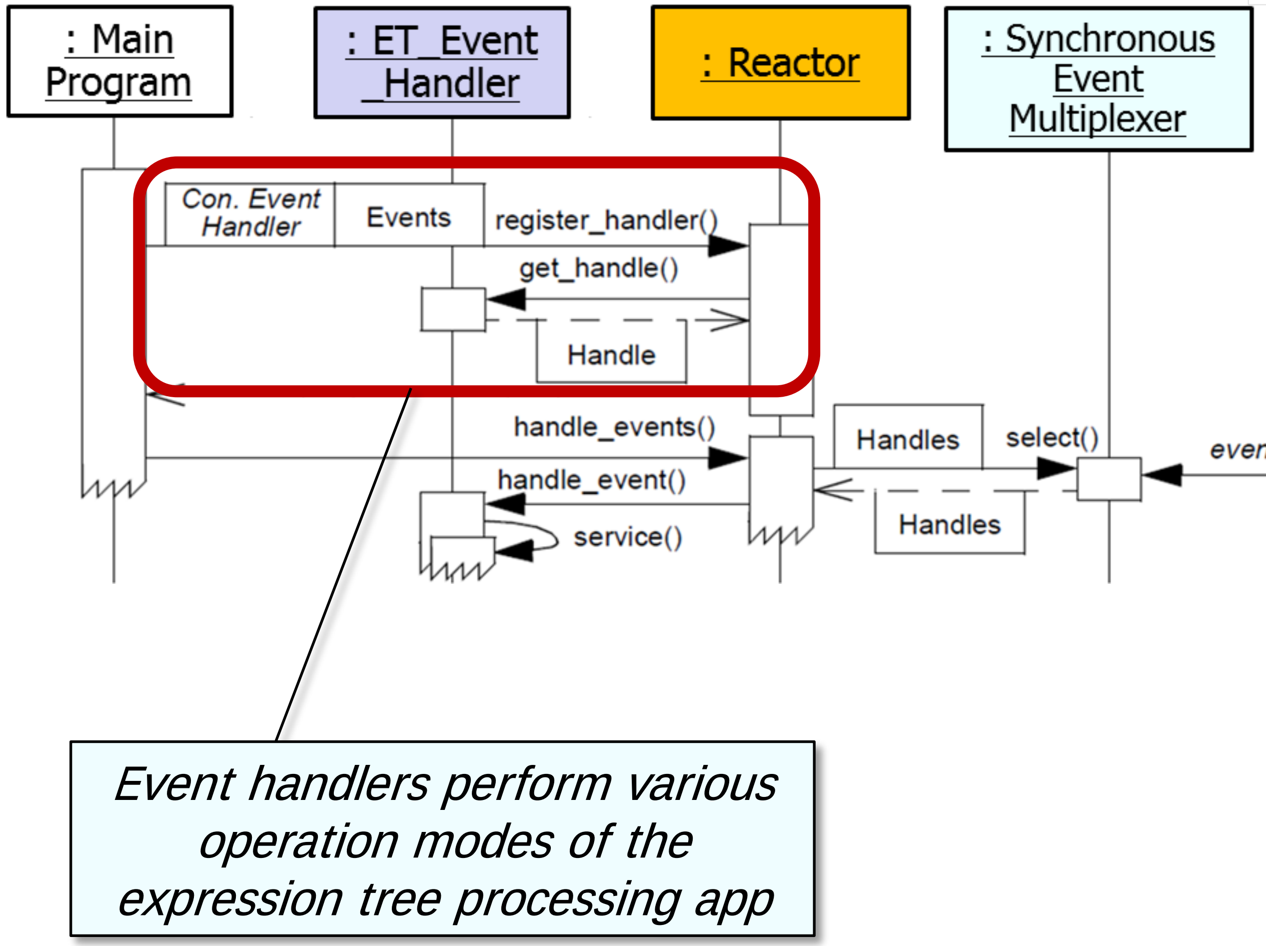
Solution: Separate Event Handling Concerns

- Create a reactor to *detect* input on various sources of events & then *demux* & *dispatch* the events to the appropriate event handlers



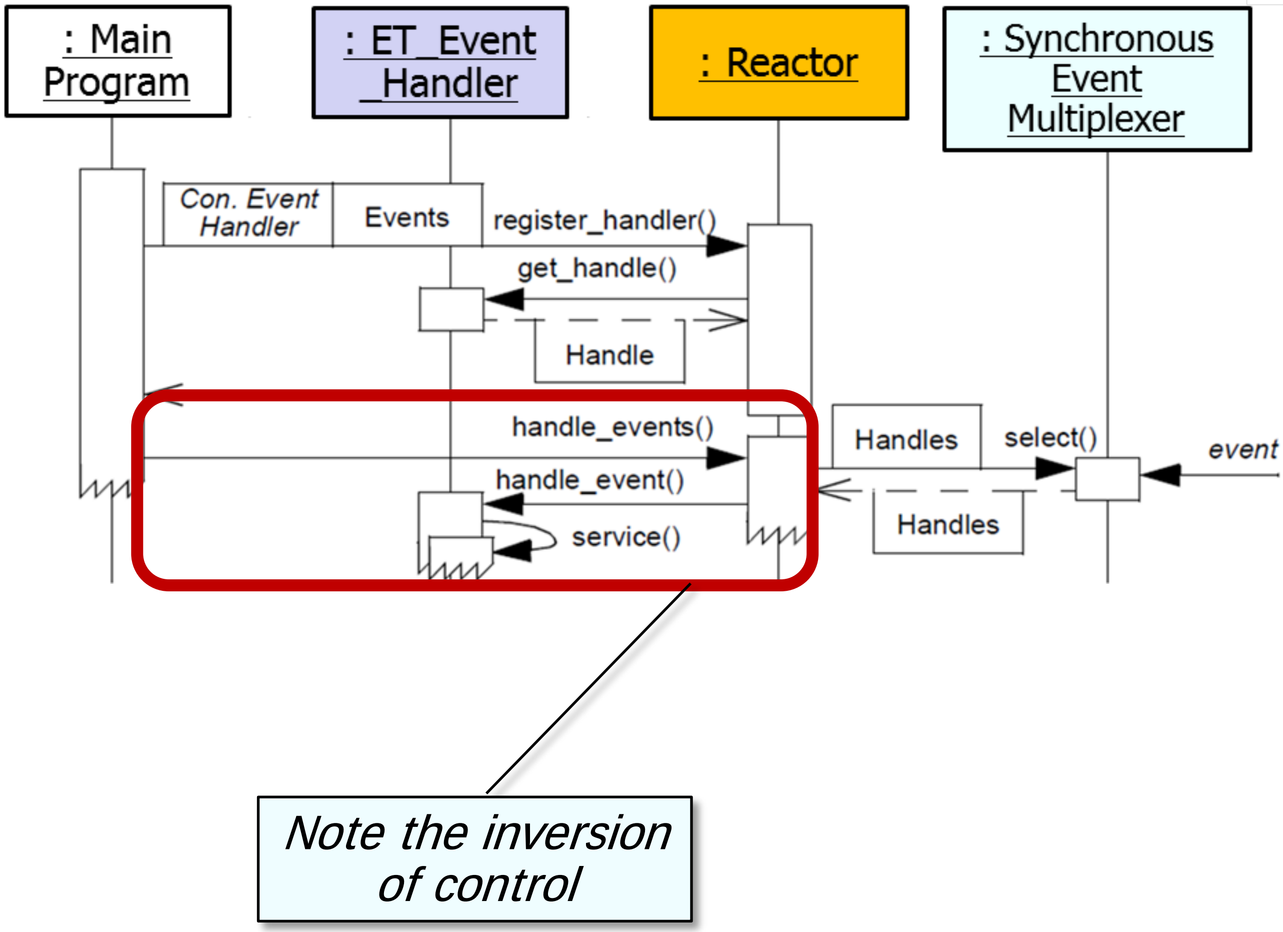
Solution: Separate Event Handling Concerns

- 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 & register the concrete event handlers with the reactor



Solution: Separate Event Handling Concerns

- 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 & register the concrete event handlers with the reactor
- Run the reactor's event loop to drive the application event flow



Reactor & Event Handler Class Interfaces

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

Interface

Enact "inversion of control"

```
          ~Reactor()
     void run_event_loop()
     void end_event_loop()
     void register_handler(Event_Handler *event_handler)
     void remove_handler(Event_Handler *event_handler)
   static
Reactor * instance()
```

Singleton access point

Attach / detact event handlers

Reactor & Event Handler Class Interfaces

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

Interface

```
            ~Reactor()
       void run_event_loop()
       void end_event_loop()
       void register_handler(Event_Handler *event_handler)
       void remove_handler(Event_Handler *event_handler)
     static
 Reactor * instance()
```

<<uses>>

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

Process an event

- **Commonality**: Provides a common interface for managing & processing events via callbacks to abstract event handlers
- **Variability**: Concrete implementations of *Reactor* & event handlers can be tailored to a wide range of OS muxing mechanisms & application-specific concrete event handling behaviors

Reactor POSA2 Architectural Pattern

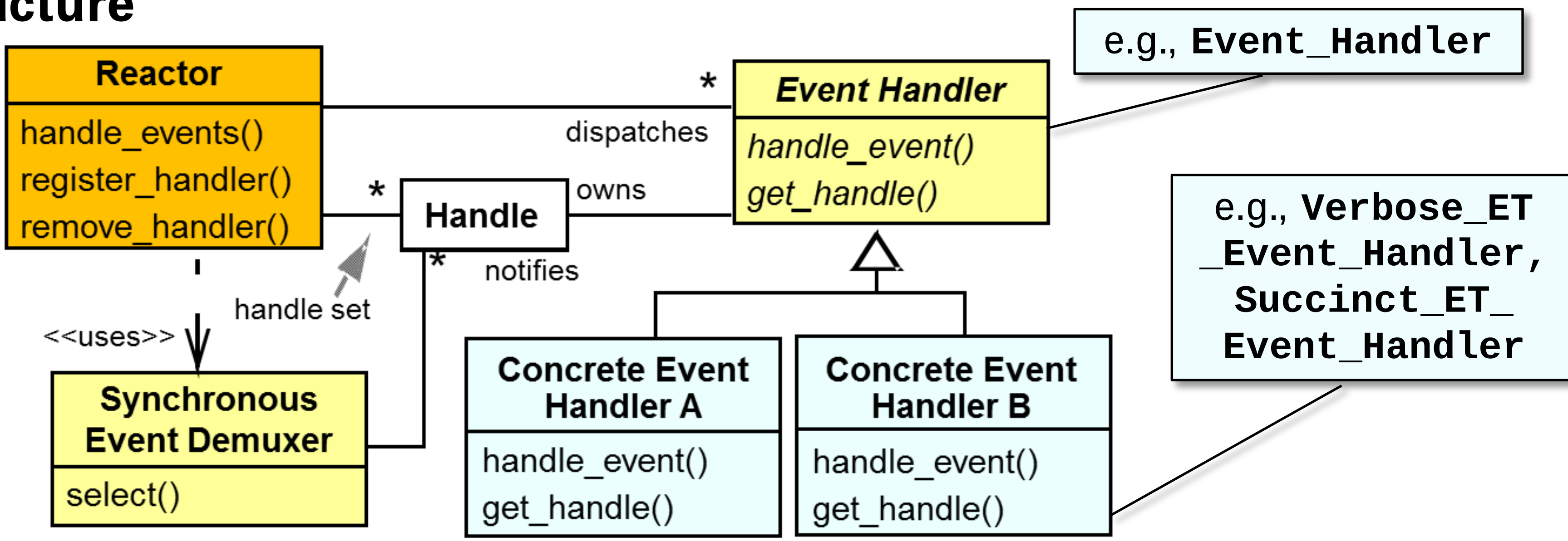
Intent

- 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 management infrastructure
- When multiple sources of events must be handled in a single thread

Structure



See www.dre.vanderbilt.edu/~schmidt/PDF/Reactor.pdf for the *Reactor* pattern

Reactor POSA2 Architectural Pattern

Reactor example in C++

- Detect/demux events & dispatch event handler callback methods in response

```
class Reactor {
public:
  static Reactor *instance();

  void run_event_loop() {
     while (run_event_loop_)
       wait_for_next_event()->handle_input();
  }

  void register_input_handler(Event_Handler *event_handler) {
    dispatch_table_.push_back(eh);
  }
  ...
private:
  std::vector <Event_Handler *> dispatch_table_;
  ...
```

Singleton access point

Run the app event loop

Register an event handler for input events in dispatch table

Reactor POSA2 Architectural Pattern

Consequences

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

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Implementation

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

Reactor POSA2 Architectural Pattern

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+ Separation of concerns & portability
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Implementation

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

Known Uses

- X Windows Xt
- InterViews Dispatcher
- ET++ WindowSystem
- AWT Toolkit
- ACE & The ACE ORB (TAO)
- Java NIO package

See gee.cs.oswego.edu/dl/cpjslides/nio.pdf for Java Reactor info

Problem: Managing Access to Global Resources

Goals

- Centralize access to resources that should be visible globally, e.g.:
  - Command-line options that parameterize the program behavior
  - Reactor that drives the main event loop

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format [in-order]
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% tree-traversal
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```

Verbose mode

Succinct mode

Problem: Managing Access to Global Resources

Goals

- Centralize access to resources that should be visible globally, e.g.:
  - Command-line options that parameterize the program behavior
  - Reactor that drives the main event loop

Constraints/forces

- Only need one instance of command-line options & event loop driver
- Global variables are problematic in C++

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```

Verbose mode

Succinct mode

Solution: Centralize Access to Global Resources

- 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

```
  ET_Event_Handler *event_handler =
    ET_Event_Handler::make_handler
      (Options::instance()->verbose());

  Reactor::instance()->register_input_handler (event_handler);
```

Register event handler with the event loop driver

```
  // ...
```

Singleton GoF Object Creational

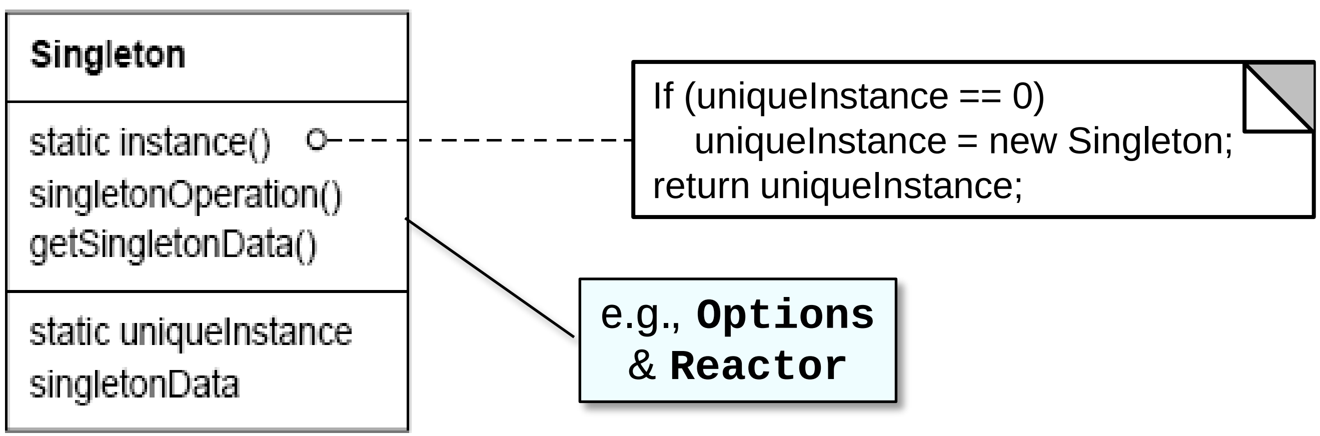
Intent

- Ensure a class only 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 GoF Object Creational

Singleton example in C++

- Define a singleton class to handle command-line option processing

```
class Options {
public:
  static Options *instance();

  // Parse command-line arguments and sets values as follows:
  // 't' - Traversal strategy, i.e., 'P' for pre-order, 'O' for
  // post-order, 'I' for in-order, & 'L' for level-order.
  bool parse_args(int argc, char *argv[]);
  bool verbose() const; // True if program runs in verbose mode.
  char traversal_strategy() // Returns desired traversal strategy
  ...

private:
  Options();
  static Options *instance_;
  ...
```

```
if (instance_ == 0)
  instance_ = new Options;
return instance_;
```

Accessor methods to check for enabled options

Make constructor private to prevent multiple instances

Points to the one & only instance

Singleton GoF 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/cache pitfalls & communication overhead

See c2.com/cgi/wiki?SingletonsAreEvil for discussion of Singleton issues

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Implementation

- Static instance operation
- Registering singleton instance with manager
- Deleting singletons

sourcemaking.com/design_patterns/to_kill_a_singleton: Singleton deletion

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Known Uses

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

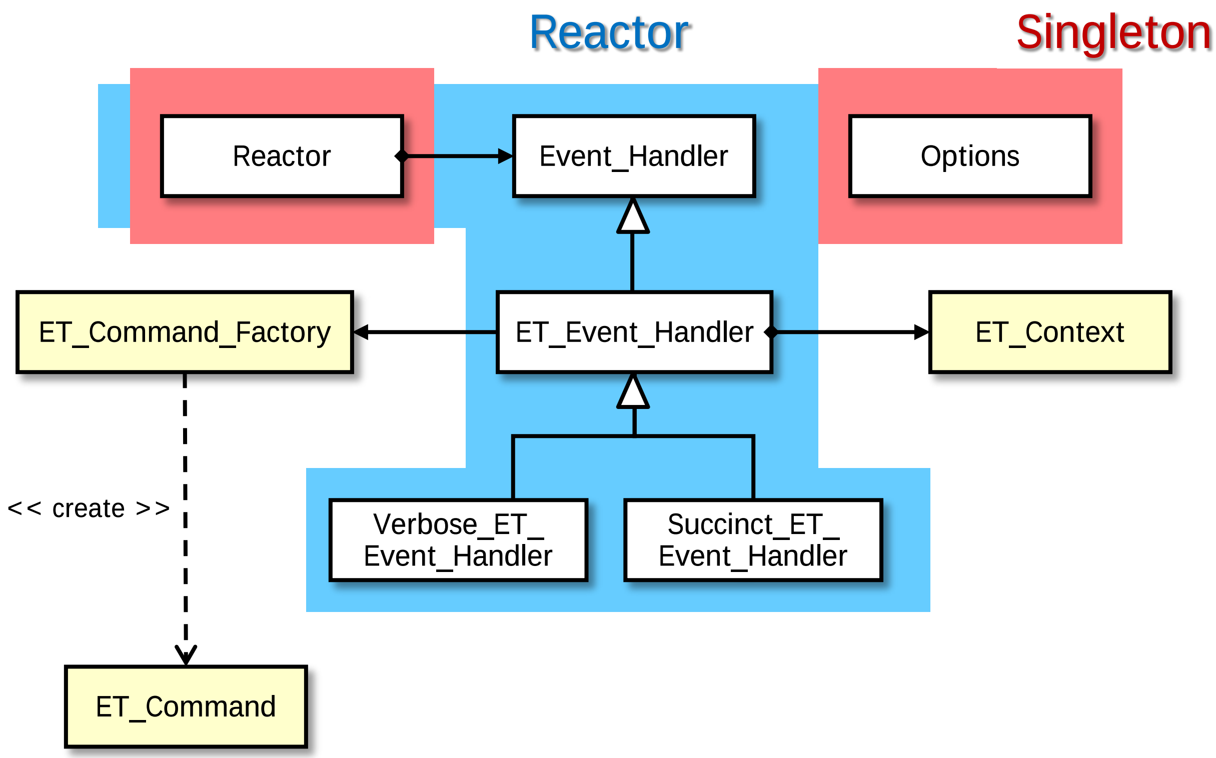
See Also

- *Double-Checked Locking Optimization pattern* from POSA2 book

en.wikipedia.org/wiki/Double-checked_locking has more synchronization info

Summary of Application Structure Patterns

Reactor structures the overall control flow of the event-driven expression tree processing app & *Singleton* simplifies access to global resources



The *Reactor* pattern embodies key characteristics of frameworks

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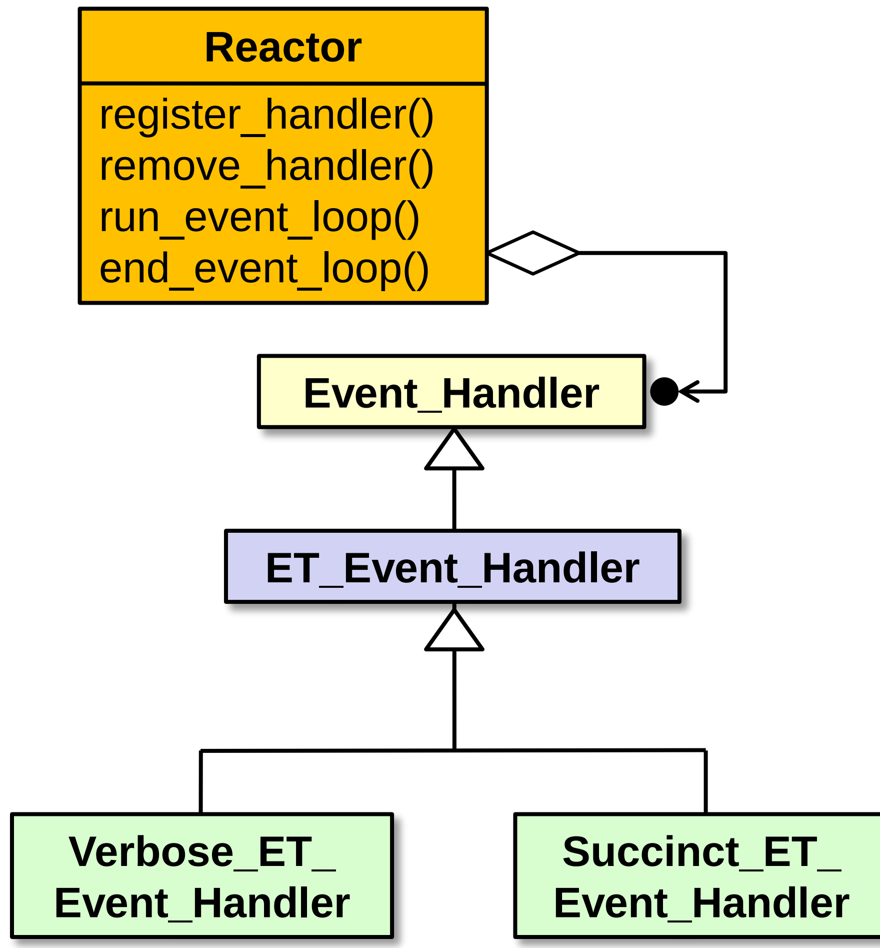
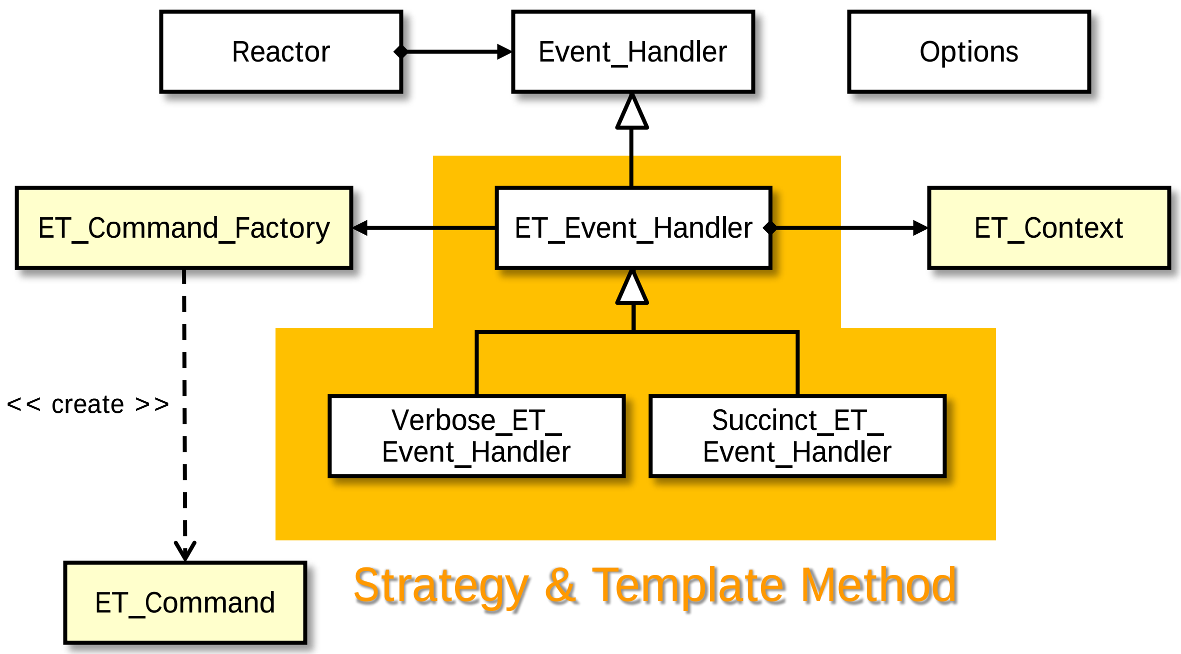
  - Commands & factories
  - Command ordering protocols
  - Application structure
  - Encapsulating algorithm variability



Overview of Algorithm Variability Encapsulation Patterns

***Purpose**: Simplify processing of multiple operation modes*



These patterns support controlled variability of steps in an algorithm

Problem: Supporting Multiple Operation Modes

Goals

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

```
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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

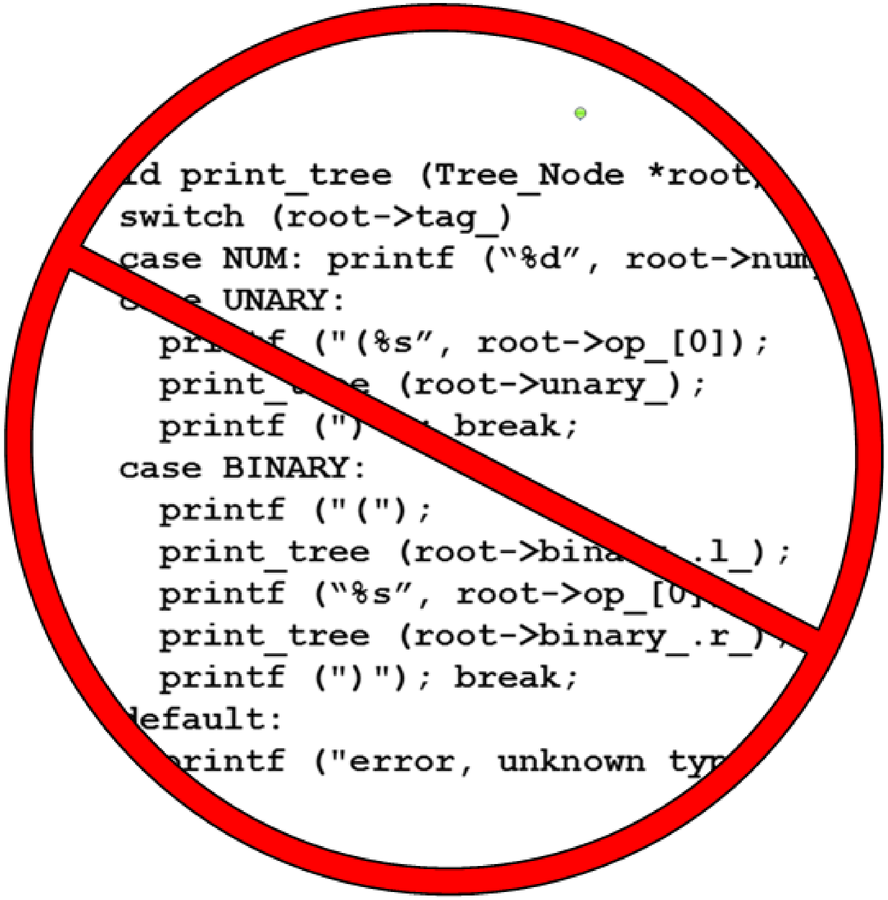
Problem: Supporting Multiple Operation Modes

Goals

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

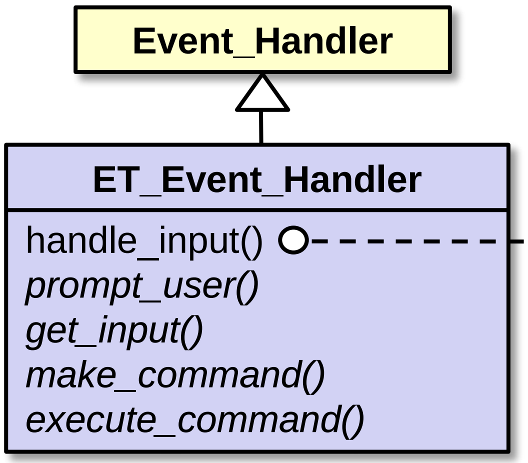
Constraints/forces

- Don't tightly couple the operation modes with the program structure
  - Simplify future enhancements
  - Avoid limitations of algorithmic decomposition



Solution A: Encapsulate Algorithm Variability

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




```
void handle_input() {
  prompt_user();
  std::string input;

  if(!get_input(input))
     Reactor::instance()->end_event_loop();

  ET_Command command
     = make_command(input);

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

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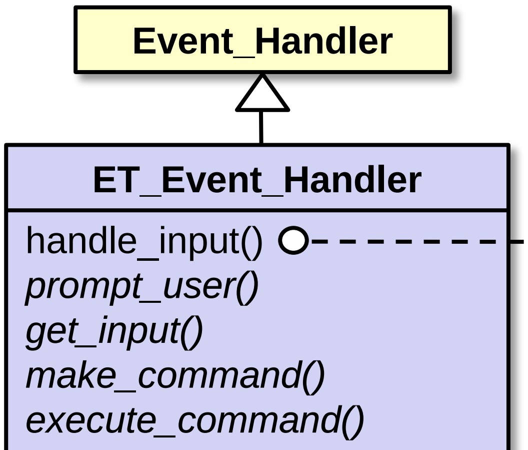


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  if(!execute_command(command))
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}
```

The other four methods are "hook methods"

handle_input() is a template method

Solution A: Encapsulate Algorithm Variability

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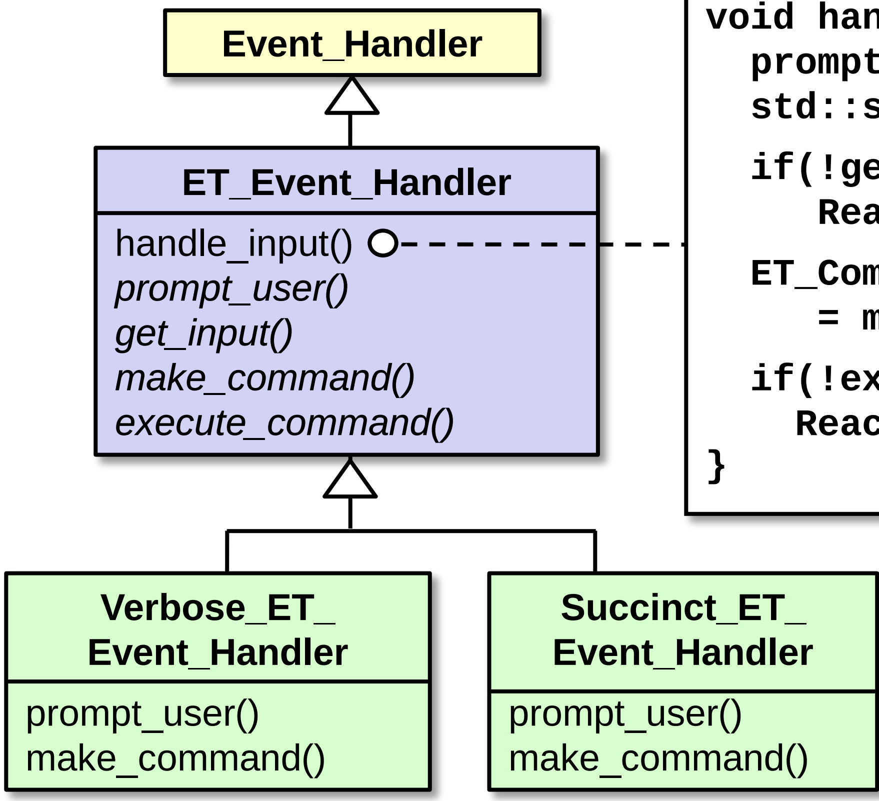


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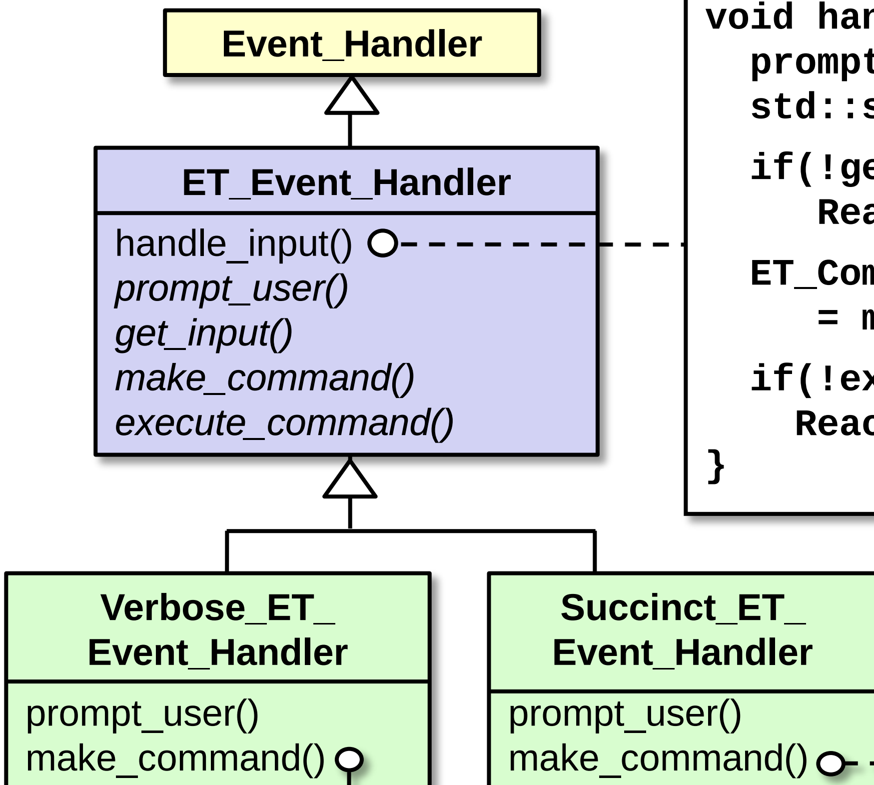


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  std::string input;

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     Reactor::instance()->end_event_loop();

  ET_Command command
     = make_command(input);

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

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

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

Customized hook methods

ET_Event_Handler Class Interface

- Provides an abstract interface for performing the algorithm associated with the expression tree processing app

Interface

Template method

Factory

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

Hook methods

- **Commonality**: Provides a common interface for handling user input events & performing steps in the expression tree processing algorithm
- **Variability**: Subclasses implement various operation modes, e.g., verbose vs. succinct mode

Template Method GoF Class Behavioral

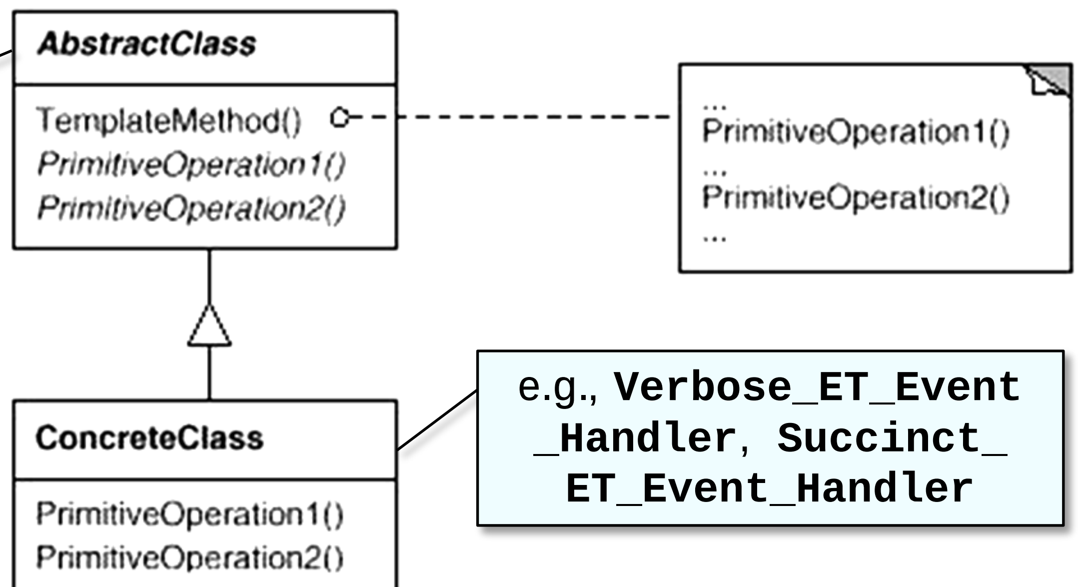
Intent

- 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



e.g., **`ET_Event_Handler`**

e.g., **`Verbose_ET_Event_Handler`**, **`Succinct_ET_Event_Handler`**

Template Method GoF Class Behavioral

Template Method example in C++

- Allow subclasses to customize certain steps in event handling algorithm

```
void ET_Event_Handler::handle_input() {
  prompt_user();
  std::string input;
  if (!get_input(input)) Reactor::instance()->end_event_loop();

  ET_Command command = make_command(input);
  if (!execute_command(command))
    Reactor::instance()->end_event_loop();
  ...
```

Template method

Hook methods

Template Method GoF Class Behavioral

Template Method example in C++

- Allow subclasses to customize certain steps in event handling algorithm

```
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  std::string input;
  if (!get_input(input)) Reactor::instance()->end_event_loop();

  ET_Command command = make_command(input);
  if (!execute_command(command))
    Reactor::instance()->end_event_loop();
  ...
ET_Command Verbose_ET_Event_Handler::make_command
                     (const std::string &input) {
  return command_factory_.make_command(input);
}
        ET_Command Succinct_ET_Event_Handler::make_command
                              (const std::string &input) {
          return command_factory_.make_macro_command(input);
        }
```

Specialized hook methods

Template Method GoF Class Behavioral

Template Method example in C++

- Allow subclasses to customize certain steps in event handling algorithm

```
void ET_Event_Handler::handle_input() {
  prompt_user();
  std::string input;
  if (!get_input(input)) Reactor::instance()->end_event_loop();

  ET_Command command = make_command(input);
  if (!execute_command(command))
    Reactor::instance()->end_event_loop();
  ...

ET_Event_Handler *ET_Event_Handler::make_handler(bool verbose) {
  return verbose ? new Verbose_ET_Event_Handler
                 : new Succint_ET_Event_Handler
}
```

Factory creates appropriate strategy objects

This is not the only (or best) way of defining a factory

Template Method GoF Class Behavioral

Consequences

+ Enables 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)

Template Method GoF Class Behavioral

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+ Enables inversion of control ("Hollywood principle: don't call us – we'll call you!")
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Implementation

- Virtual vs. non-virtual template method
- Few vs. many primitive operations (hook methods)
- Naming conventions (do_*() vs. make_*() prefix)

Template Method GoF Class Behavioral

Consequences

+ Enables inversion of control ("Hollywood principle: don't call us – we'll call you!")

+ Promotes code reuse

+ Lets you enforce overriding rules

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Implementation

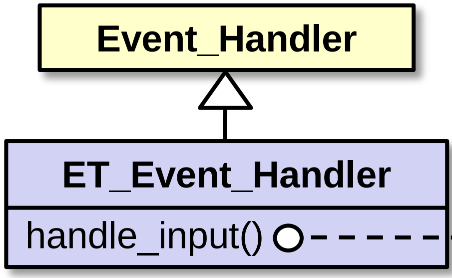
- Virtual vs. non-virtual template method
- Few vs. many primitive operations (hook methods)
- Naming conventions (do_*() vs. make_*() prefix)

Known Uses

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

Solution B: Encapsulate Algorithm Variability

- Implement algorithm once in base class & let strategies define variant parts

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  std::string input;

  if(!get_input(input))
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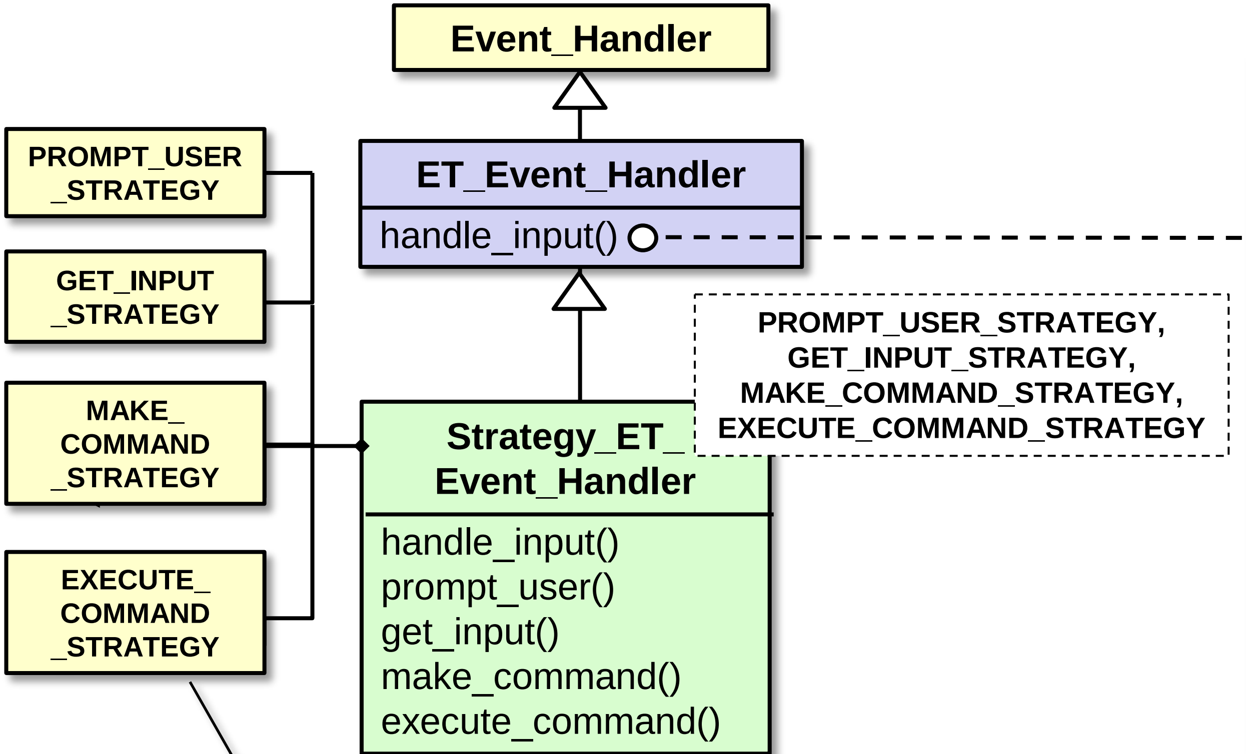
  ET_Command cmd
    = make_command(input);

  if(!execute_command(cmd))
    Reactor::instance()
      ->end_event_loop();
}
```

Same template method & hook methods as before

Solution B: Encapsulate Algorithm Variability

- Implement algorithm once in base class & let strategies define variant parts

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```

Strategy objects can be passed as arguments to ***`Strategy_ET_Event_Handler`*** *constructor*

Solution B: Encapsulate Algorithm Variability

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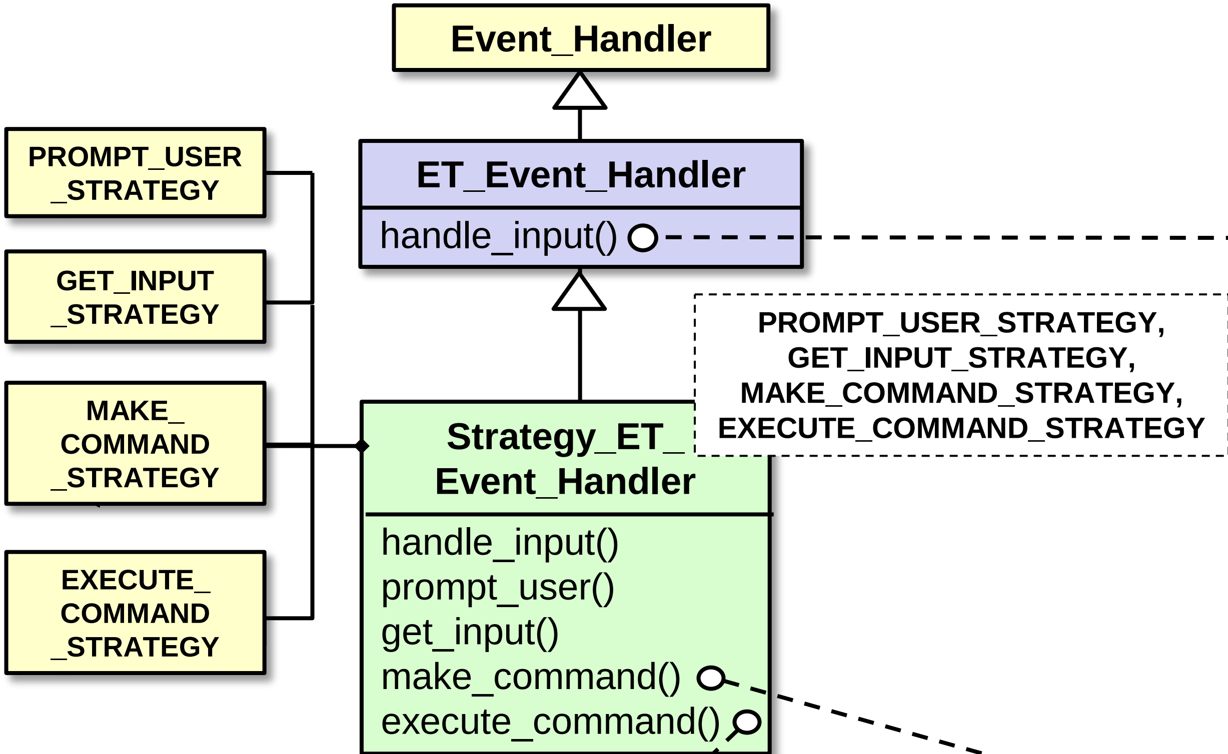


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  if(!execute_command(cmd))
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}
```

Hook methods forward to strategy object methods

```
ET_Command make_command(const std::string &input)
{ return mc_strategy_.make_command(input); }
```

```
bool execute_command(const std::string &input)
{ return ec_strategy_.execute_command(input); }
```

Strategy Template Parameters

- Provides template parameters that perform steps in the algorithm associated with the expression tree processing app

Template Parameters

```
MAKE_COMMAND
   _STRATEGY
  ET_Command make_command(const std::string &input)

EXECUTE_COMMAND
   _STRATEGY
         bool execute_command(const std::string &input)
              ...
```

Expected method signatures

- **Commonality**: Provides common expected method signatures for performing steps in the expression tree processing algorithm
- **Variability**: Template arguments provided to **`Strategy_ET_Event_Handler`** implement various operation modes, e.g., verbose vs. succinct

Strategy GoF Object Behavioral

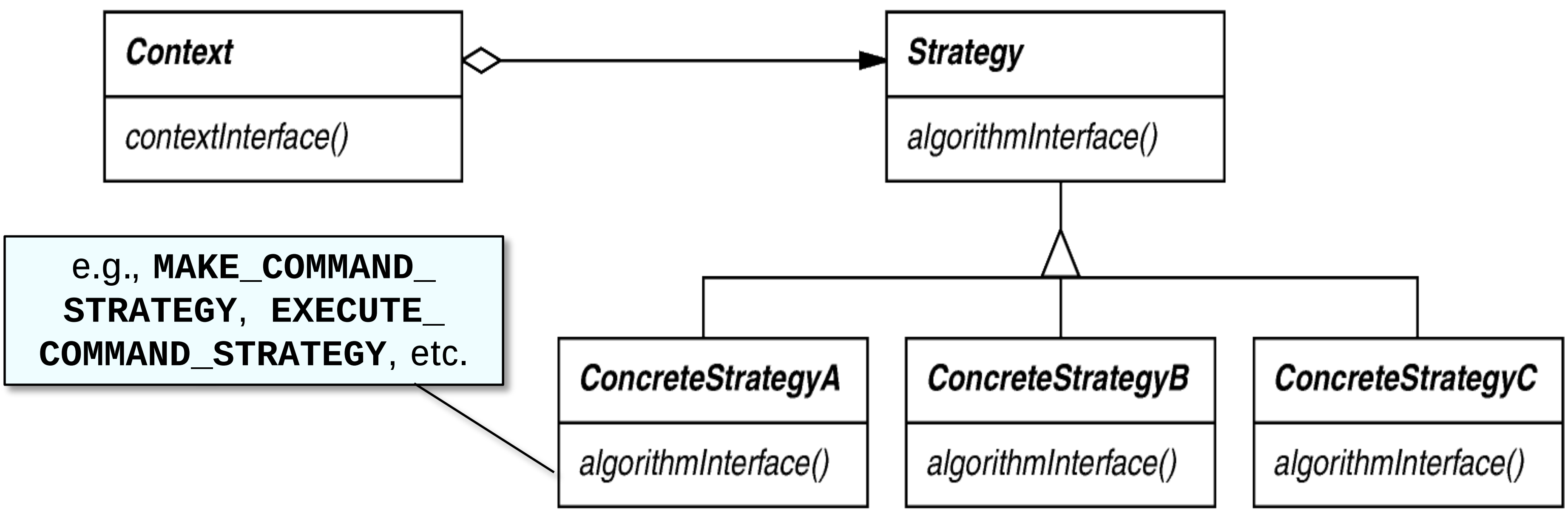
Intent

- 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 GoF Object Behavioral

Strategy example in C++

- Customize algorithm behavior by composition/forwarding vs. inheritance

```
template <..., typename MAKE_COMMAND_STRATEGY,
          typename EXECUTE_COMMAND_STRATEGY>
class Strategy_ET_Event_Handler : public ET_Event_Handler {
public:
  Strategy_ET_Event_Handler
   (...,
    const MAKE_COMMAND_STRATEGY &mc_strategy,
    const EXECUTE_COMMAND_STRATEGY &ec_strategy) ...
```

Parameterized type strategies

Reuse handle_input() template method

Pass strategy objects via constructor & assign to corresponding data members

Note combination of *Template Method* & *Strategy* patterns

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class Strategy_ET_Event_Handler : public ET_Event_Handler {
public:
  Strategy_ET_Event_Handler
   (...,
    const MAKE_COMMAND_STRATEGY &mc_strategy,
    const EXECUTE_COMMAND_STRATEGY &ec_strategy) ...
  ...

  ET_Command make_command(const std::string &user_input)
  { return mc_strategy_.make_command(user_input); }
```

Hook methods forward to strategy objects

```
  bool execute_command(ET_Command &command)
  { return ec_strategy_.execute_command(command); }
```

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class Strategy_ET_Event_Handler : public ET_Event_Handler {
public:
  Strategy_ET_Event_Handler
   (...,
    const MAKE_COMMAND_STRATEGY &mc_strategy,
    const EXECUTE_COMMAND_STRATEGY &ec_strategy) ...
 ...

class Macro_Command_Strategy {
public:
   ...
   ET_Command make_command(const std::string &input)
   { return command_factory_.make_macro_command(input); }
};
```

Will be used as argument to the `Strategy_ET_Event_Handler` parameterized type

Creates a macro command

Strategy GoF Object Behavioral

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          typename EXECUTE_COMMAND_STRATEGY>
class Strategy_ET_Event_Handler : public ET_Event_Handler {
public:
  Strategy_ET_Event_Handler
   (...,
    const MAKE_COMMAND_STRATEGY &mc_strategy,
    const EXECUTE_COMMAND_STRATEGY &ec_strategy) ...
 ...
```

Factory creates appropriate strategy objects

```
ET_Event_Handler *Strategy_ET_Event_Handler::make_handler
                                        (bool verbose) {
  return verbose ? new Strategy_ET_Event_Handler
                         <..., Command_Strategy, ...>
                 : new Strategy_ET_Event_Handler
                         <..., Macro_Command_Strategy, ...>
}
```

Strategy GoF Object Behavioral

Consequences

+ Greater flexibility, reuse
+ Can change algorithms dynamically
– Strategy creation & communication overhead
– Inflexible Strategy interface
– Semantic incompatibility of multiple strategies used together

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Implementation

- Exchanging information between a strategy & its context
  - Context is not always necessary
- Static binding of strategy selection via parameterized types

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Known Uses

- InterViews text formatting
- RTL register allocation & scheduling strategies
- ET++SwapsManager calculation engines
- The ACE ORB (TAO) real-time object request broker middleware

See Also

- *Bridge* pattern (object structural)

Comparing Strategy with Template Method

Strategy

+ Provides for clean separation between components via "black-box" interfaces
+ Allows for strategy composition at runtime
+ Supports flexible mixing & matching of features
– Incurs the overhead of forwarding
– May yield many strategy classes

Comparing Strategy with Template Method

Strategy

+ Provides for clean separation between components via "black-box" interfaces
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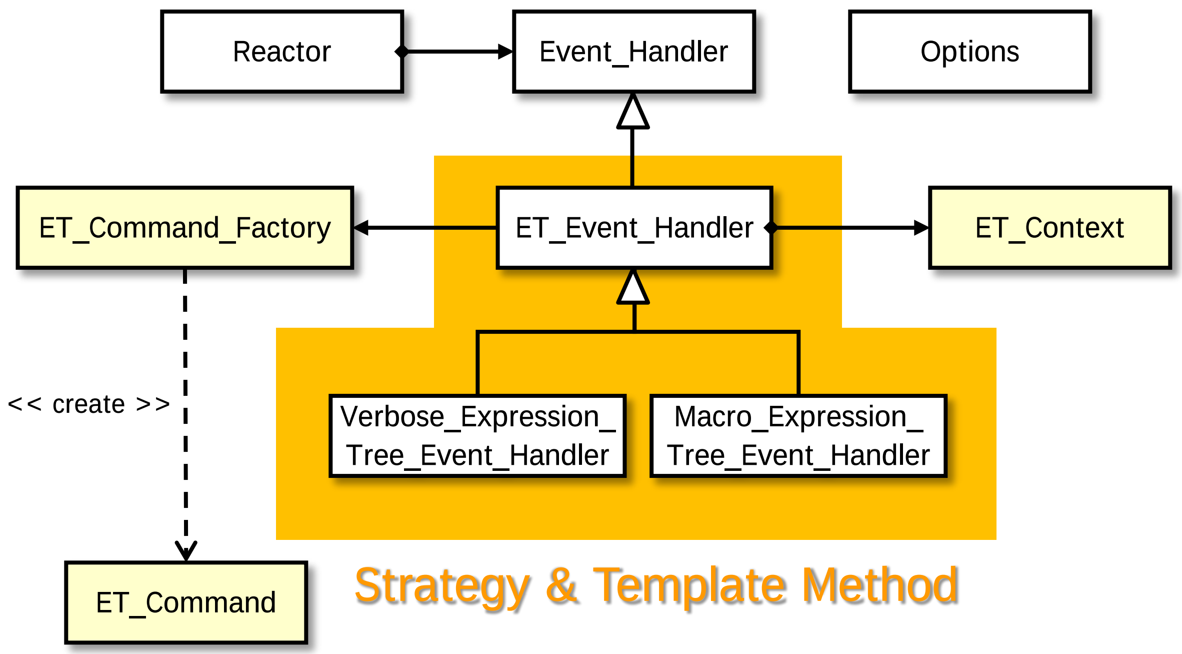
Template Method

+ No explicit forwarding necessary
+ May be easier for small use cases
– Close coupling between subclass(es) & base class
– Inheritance hierarchies are static & cannot be reconfigured at runtime
– Adding features via inheritance may yield combinatorial subclass explosion
  – Beware overusing inheritance since it's not always the best choice
  – Deep inheritance hierarchies in an app are a red flag

Strategy is commonly used for Black-box frameworks
Template Method is commonly used for White-box frameworks

Overview of Algorithm Variability Encapsulation Patterns

The *Strategy* & *Template Method* patterns simplify processing of multiple operation modes



These patterns avoid limitations of algorithmic decomposition