C++ now

Dependency Injection in C++

A Practical Guide

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Engineering

Who Am I?

- Started using C++ professionally in 1991
- Professional Career
  - Systems Analyst & Architect
  - 21 years as a consultant
  - Bloomberg Ticker Plant Engineering Lead
- Talks focus on practical Software Engineering
  - Based in the real world
  - Demonstrate applied principles
  - Take something away and be able to use it

Questions

#include <slide_numbers>

Where will we absolutely not be going?

- All kinds of talk about interfaces and function contracts
- Examine various automatic dependency Injection Frameworks
- Talk is rooted in toy example systems and theory
- Bunch of high brow talk about keeping everything as a passed in parameter

NOPE

Where will we be going ?

- Talk will be about ***using*** Dependency Injection in applications
- Using various DI methods to achieve functionality swapping / instrumentation for flexibility and testability
- Focus on strategies / How to think to achieve DI in the real world without undue warping of Production Code (or just giving up).
- Talk is rooted in a real world systems not theory

Dependency Injection Myths

Dependency Injection Myths :

- It’s simple
- Only for simplistic systems or small parts of real systems
- Overkill on smaller projects
- Forget for now, Easy to add in later
- Only for testing *

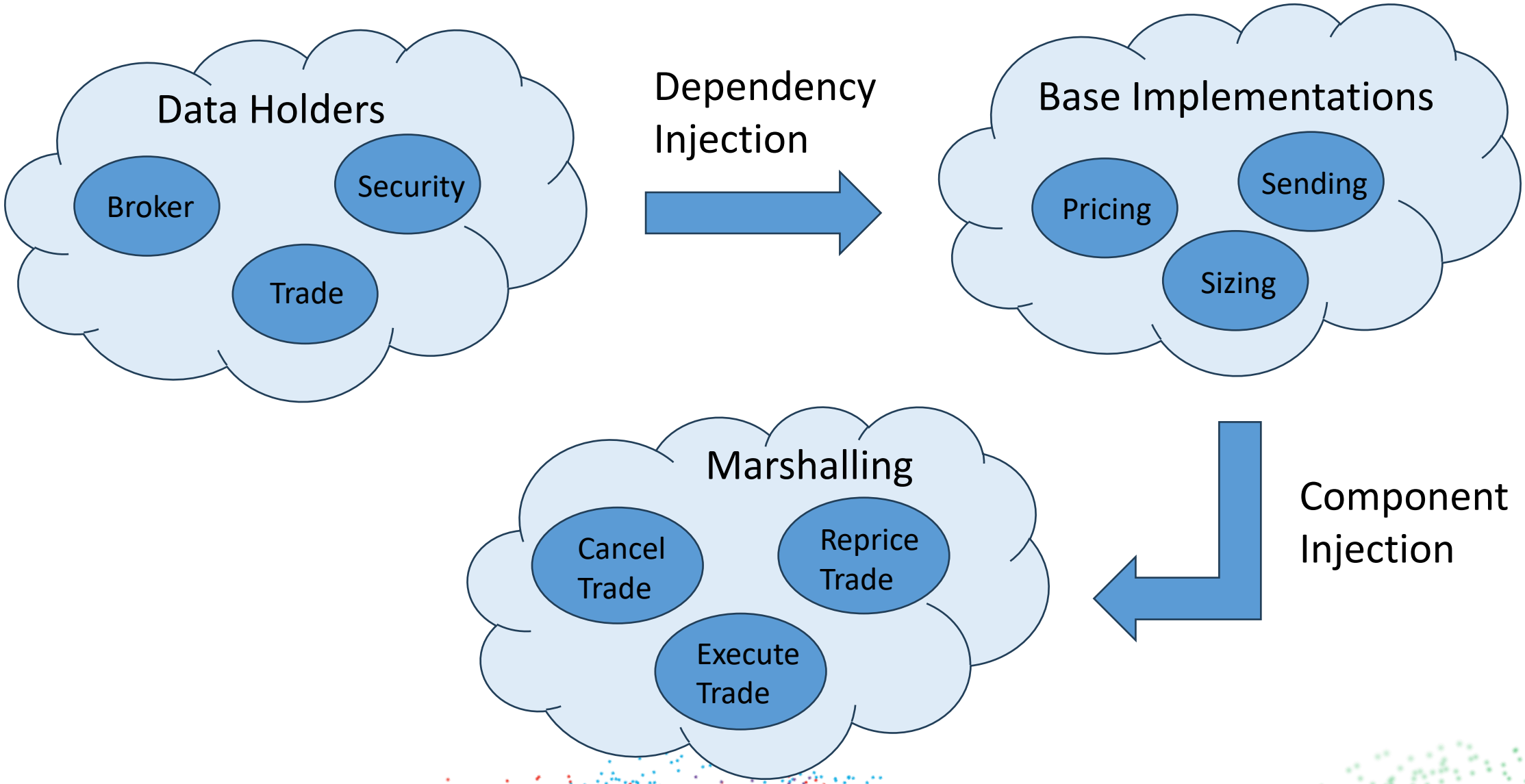
Testing without Dependency Injection

Pocket Universe Testing :

Setup a (barely) functional full environment :

- Set up toy configs , databases, components, etc to have a usually barely functional “Full environment” and test
- Testing is ***not*** unit testing as it engages all parts of the system simultaneously aka integration testing.
  - ❑ Lack of specificity
  - ❑ More difficult setup / error investigation
  - ❑ Can lean entirely on regression A/B testing

What is the essence of Dependency Injection?



Dependency Injection Basics

Methods to inject different functionality

- linking

Link-time Dependency Injection

Uses Link-time switching of functionality

- Allows limited Testing
- No code changes/contamination in actual production application required
- The code using the dependent functionality has no say in which implementation is being executed.
  - ❑Externally Injected during compilation via LIBPATH or #IFDEF

Link-time Dependency Injection

Twin implementations :

- One for Production
  - Real Functionality linked in with all of the real dependencies
- One for Testing
  - Simple implementation of some Test classes / functions
  - Alternate implementation files(.cpp) live in a alternate/test code branch.
  - One link, one testing scenario

Link-time Dependency Injection

```cpp
// ActionHandler.cpp
struct ActionHandler {
  Coms coms_;

  void execute(const Action&) {
    Request req;
    //...
    auto result = coms_.send(req);
    check_response(result);
  }
};
```

Dependency

```cpp
// Com.cpp

 Result Com::send(const Request& req) {
   ...
   return result;
 }
```

```cpp
/* Test/Com.cpp */
   Request global_req;

 Result Com::send(const Request& req) {
   global_req = req;
   return fixed_result;
 }
```

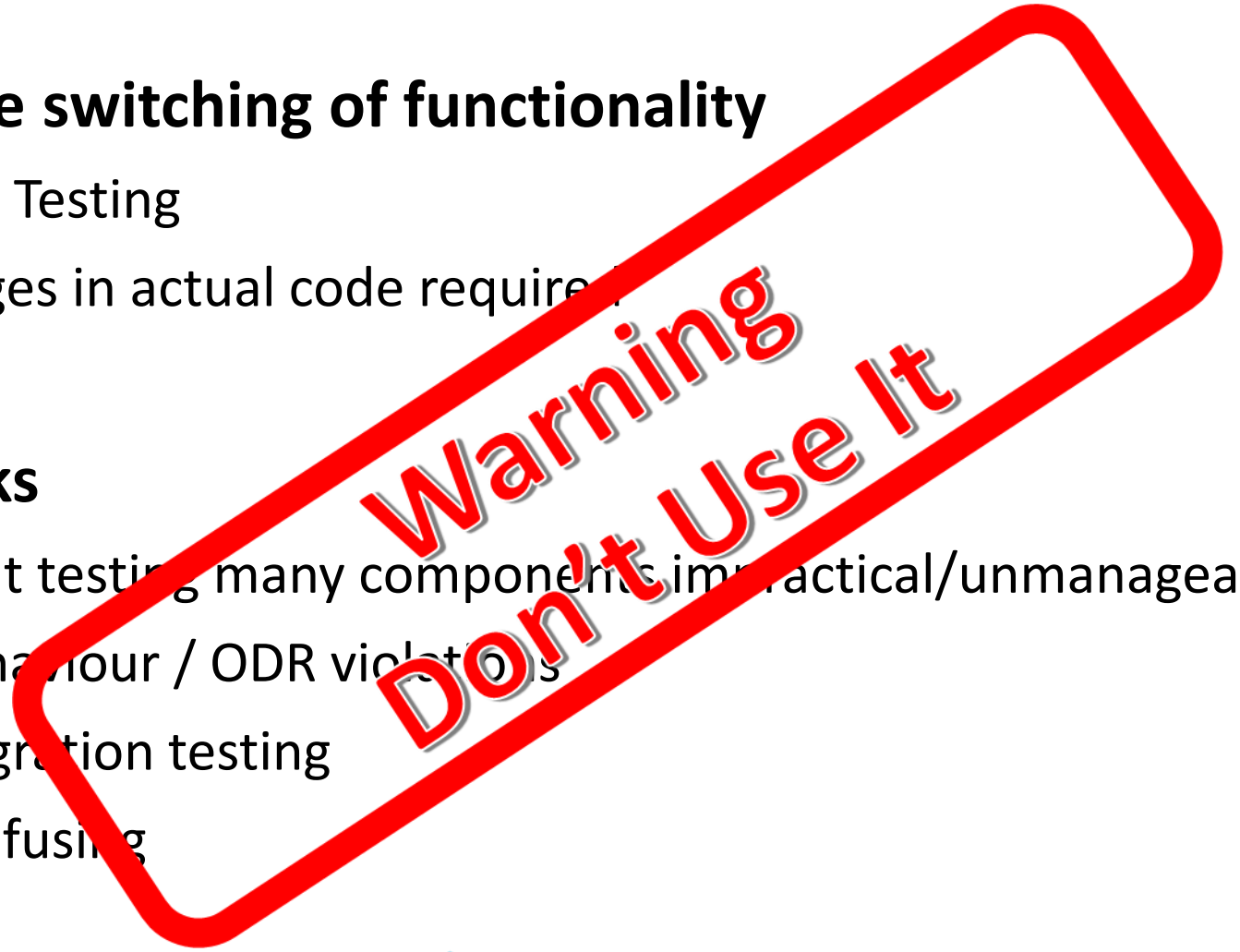
Link-time Dependency Injection

Uses Link-time switching of functionality

- Allows Limited Testing
- No code changes in actual code required

The Drawbacks

- Logistics of unit testing many components impractical/unmanageable
- Undefined Behaviour / ODR violations
- More like Integration testing
- Brittle and confusing



Dependency Injection Basics

Methods to inject different functionality

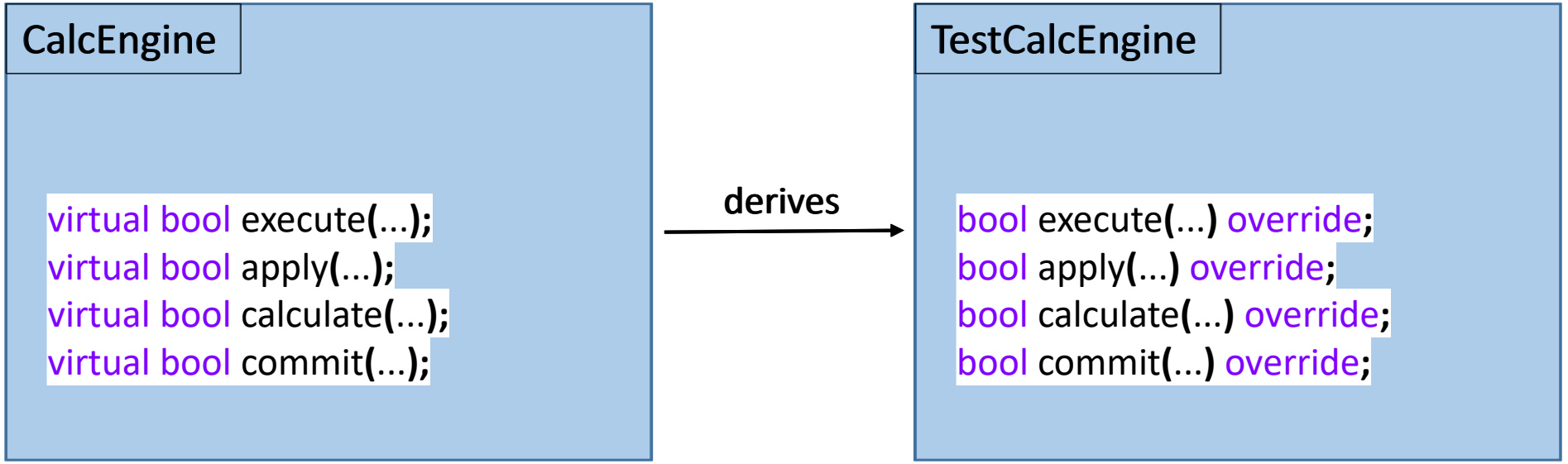
- ~~Linking~~
- Inheritance/virtual functions

Dependency Injection via inheritance

Create a base class interface or extend from an existing Class

- Can handle lots of methods
  - Rich interface
- Well understood mechanism
  - Virtual functions + override
- Easier to add to older codebases

Dependency Injection via inheritance

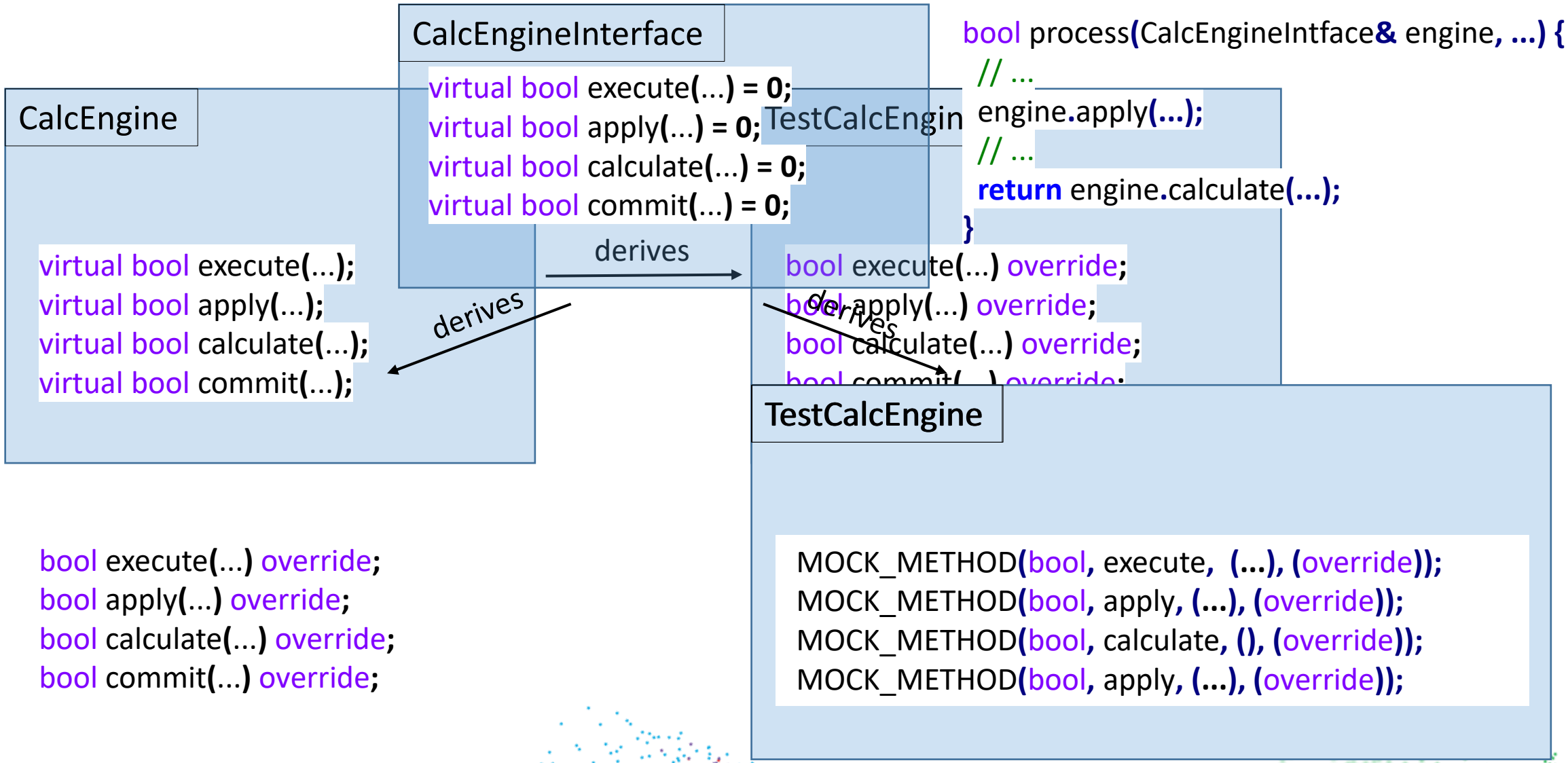



```
bool process(CalcEngine& engine, ...){
  // ...
  engine.apply(...);
  // ...
  return engine.calculate(...);
}
```

Injection

Testing

Dependency Injection via inheritance



Dependency Injection via inheritance

Create an interface or extend from Class

- Can handle lots of methods being mocked
  - Rich interface
- Easy to add to older codebases

Drawbacks

- Interface can become messy or has purely test functions added
  - Pure virtual functions can be numerous and a nightmare to stub out
  - Data mixed in with interfaces
  - Uses virtual function table so extra hop

Dependency Injection Basics

Methods to inject different functionality

- ~~Linking~~
- Inheritance/virtual functions
- Templates

Dependency Injection via templates

Create a Class that satisfies the calls made on the class by the function

- Can handle lots of methods being mocked
  - Only need to define the methods actually used
- Compile time so no runtime virtual calls overhead
- Can use concepts(C++20) to define an “interface”

Dependency Injection via templates

```
template<typename CalcEngine>
bool process(CalcEngine& engine) {
  // ...
  engine.apply(rdata);
  rdata.data_ = "2";
  // ...
  return engine.calculate(rdata);
}
```

Injection

Dependency

```
struct RealCalcEngine {
  RealCalcEngine(...);

  bool apply(const Data& rdata);
  bool calculate(const Data& rdata);
};
```

```
struct TestCalcEngine {
  TestCalcEngine();

  MOCK_METHOD(bool, apply, (const Data&));
  MOCK_METHOD(bool, calculate, (const Data&));
};
```

Dependency Injection via templates

```
template<CalcEngineT CalcEngine>
bool process(CalcEngine& engine) {
  // ...
  engine.apply(rdata);
  rdata.data_ = "2";
  // ...
  return engine.calculate(rdata);
}
```

```
template <typename T>
concept CalcEngineT = requires(T t, const Data& d) {
   {t.calculate(d)} -> std::convertible_to<bool>;
   {t.apply(d)} -> std::convertible_to<bool>;
};
```

```
struct RealCalcEngine {
  RealCalcEngine(...);

  bool apply(const Data& rdata);
  bool calculate(const Data& rdata);
};
```

```
struct TestCalcEngine {
  TestCalcEngine();

  MOCK_METHOD(bool, apply, (const Data&));
  MOCK_METHOD(bool, calculate, (const Data&));
};
```

Dependency Injection via templates

Create a Class - aka a concept - that satisfies the calls made on the class

- Can handle lots of methods being mocked
- Compile time so no runtime virtual calls overhead

Drawbacks :

- Templates all the way down
  - Hard to add in legacy code
- Increased compilation times
- More hieroglypical

Dependency Injection Basics

Methods to inject different functionality

- ~~Linking~~
- Inheritance/virtual functions
- Templates
- Type erasure

Dependency Injection via type erasure

Call any thing satisfying a function signature – via std::function/std::move_only_function/std::invoke

- Invokable on any callable target
- Versatile

Dependency Injection via type erasure

```
using CalculateYield = std::function<double(const Data&, ...)>;
```

Dependency Type

```
struct YieldProcessor {
  Processor(CalculateYield yield_calc) : YieldCalculator_(std::move(yield_calc)){};
  // ...
  auto process(Data& data){
    // ...
    auto yield = YieldCalculator_(data, ...);
    // ...
    return yield;
  }
private :
  CalculateYield YieldCalculator_;
};
```

Injection

Testing

Dependency

Dependency Injection via type erasure

```
TEST(Processor, test_yield) {

auto y_calculator = [] (const YieldData& ydata){ return ydata.data_*0.01;};

YieldProcessor processor(y_calculator);

YieldData rdata{100};

auto yield = processor.process(rdata);
EXPECT_EQ(yield.realised, 1);
}
```

Dependency

Injection

Testing

Verification

Dependency Injection via type erasure

Call any function satisfying a function signature – via std::function/std::move_only_function/std::invoke

- Invokable on any callable target
- Versatile

Drawbacks

- Can handle only the one method being substituted
- Can’t substitute for a class instance
- Similar overhead to runtime virtual calls

Dependency Injection Basics

Methods to inject different functionality

- ~~linking~~
- Inheritance/virtual functions
- Templates
- Type erasure

➢Null valued objects / stubs

Null Valued Objects

A stub with no functionality - only satisfying the type requirements

- Disables a part(s) of the system not under test
  - Null pointers/std::unique_ptr/std::shared_ptr – with checks – could do the same
  - Null references are illegal, so a stub is needed
- Supplies the correct type but no actual implementation logic
  - Supplied arguments discarded
  - Returns fixed values

Null Valued Objects

DBInterface

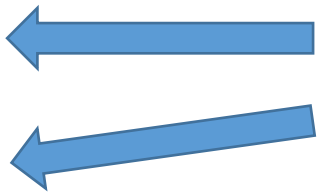
```
virtual bool commit(...) = 0;
virtual bool rollback(...) = 0;
virtual bool statement(...) = 0;
```

derives

NullDB

```
bool commit(...) override { return true;}
bool rollback(...) override { return true;}
bool statement(...) override { return true;}
```

```
auto process(DBInterface& db, ...) {
  // ...
  db.apply(...);
  // ...
  db.commit(...);
  return results;
}
```



Disabled via NullDB

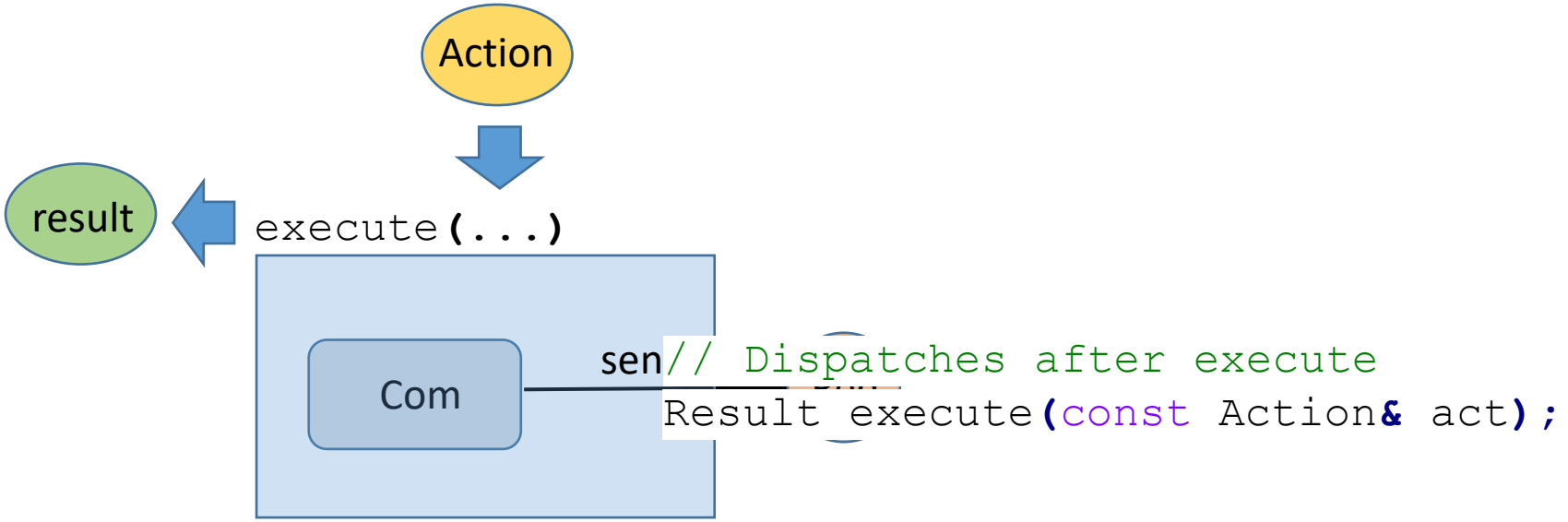
Dependency Injection Basics

Methods to inject different functionality

- ~~Linking~~
- Inheritance/virtual functions
- Templates
- Type erasure

➢Null valued objects / stubs

Dependency Injection Basics



Dependency Injection Basics

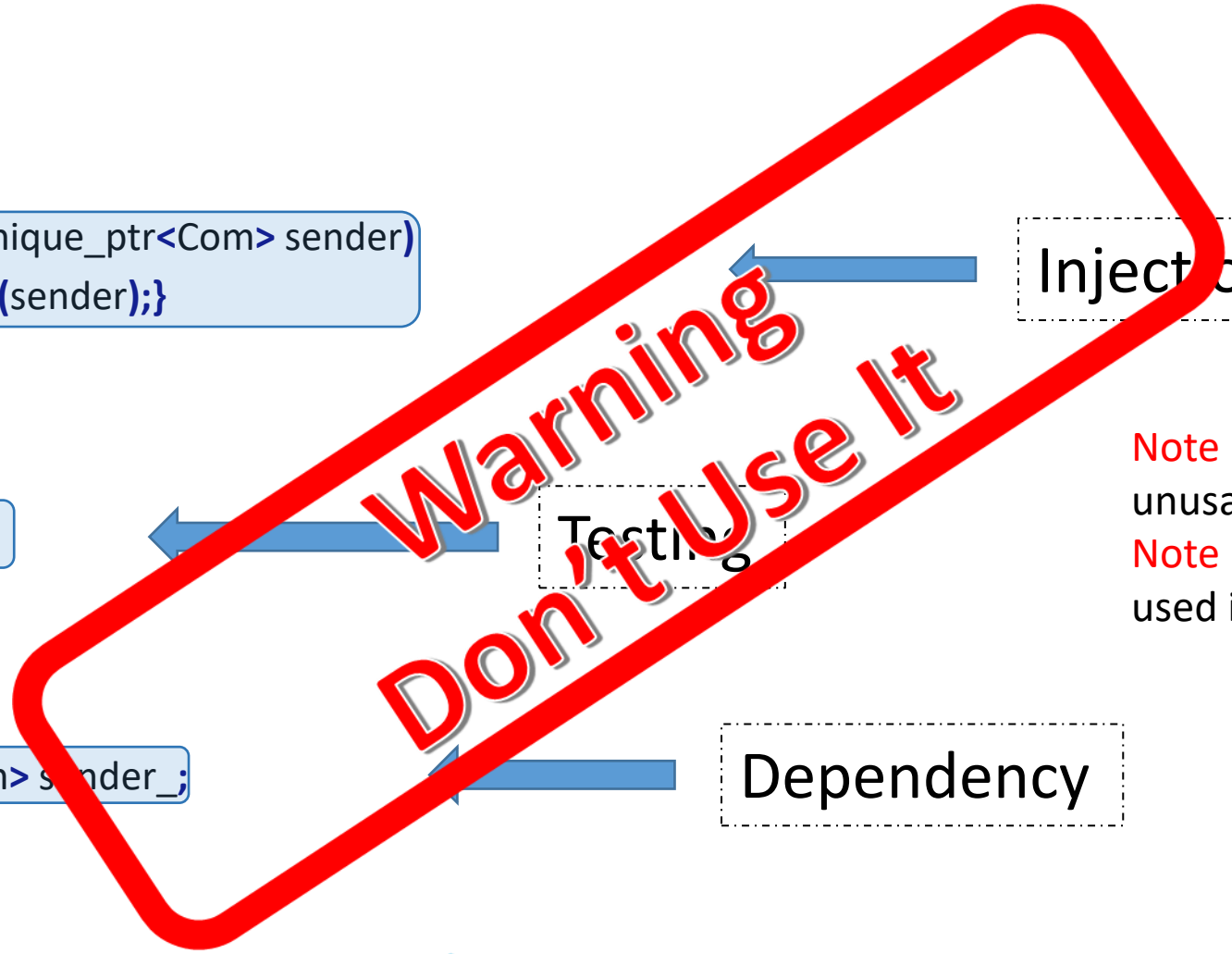
Types of Dependency Injection :

- ❑Setter Dependency Injection

Setter Dependency Injection

```
class DataProcessor {
 public:
 void setSender(std::unique_ptr<Com> sender)
  {sender_= std::move(sender);}

 bool execute(){
     ...
     sender_->send(...);
     ...
  }
 private:
  std::unique_ptr<Com> sender_;
};
```



Note : Class spends time in an unusable state

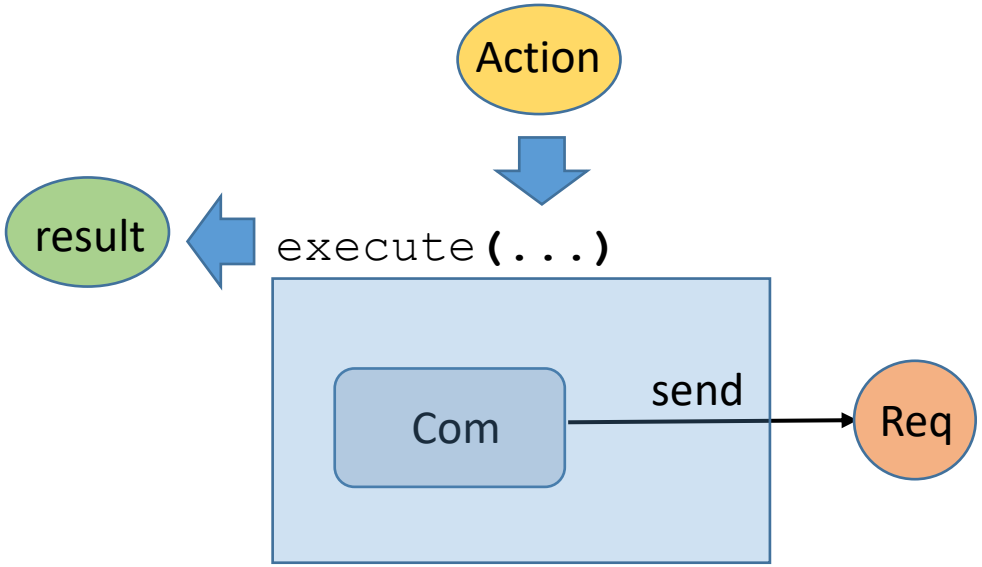
Note : Function probably not used in Production

Dependency Injection Basics

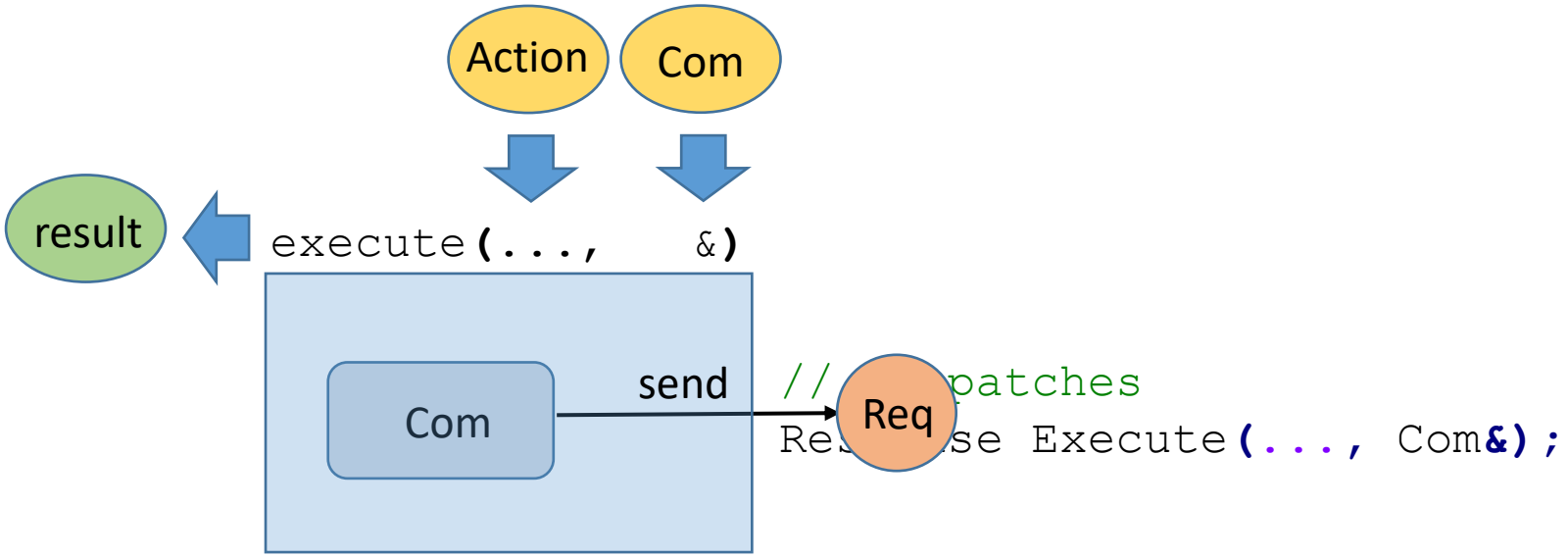
Types of Dependency Injection :

- ~~Setter Dependency Injection~~
- Method Injection

Dependency Injection Basics



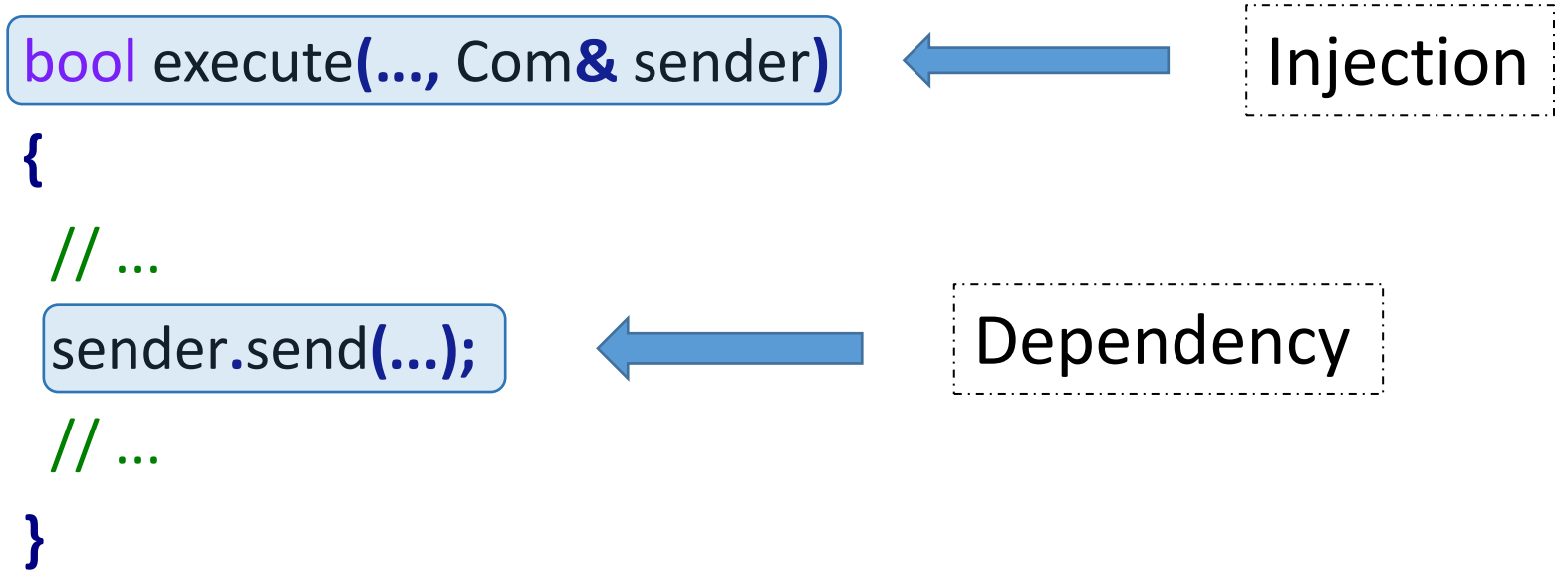
Method Dependency Injection



Method Dependency Injection

Method dependency Injection

Note : Function signature has changed

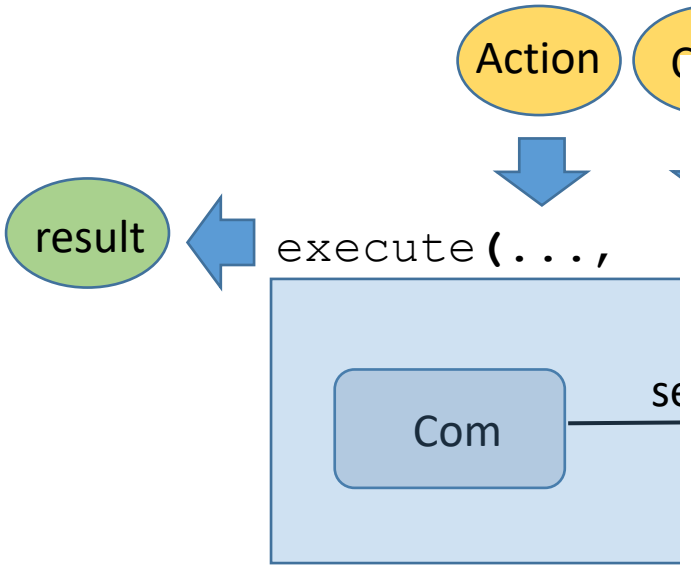


Dependency Injection Basics

Types of Dependency Injection :

- ~~Setter Dependency Injection~~
- Method Injection
- Constructor Injection

Dependency Injection Basics




```
class Processor {
 public:
  // Constructors
  Processor(..., Com& com);

  // Dispatches
  Response Execute(...);
  ...
 private:
  Com& com_;
};
```

Injection

Dependency

Constructor Dependency Injection

Constructor dependency Injection

Note : function signature unchanged
Note : Constructor signature has changed

```
class DataProcessor {
 public:

  DataProcessor(...,Com& sender) : sender_(sender){...}

  bool process(...)
  {
    // ...
    sender_.send(...);
    // ...
  }
 private:
  Com& sender_;
};
```

Injection

Testing

Dependency

Dependency Injection Basics

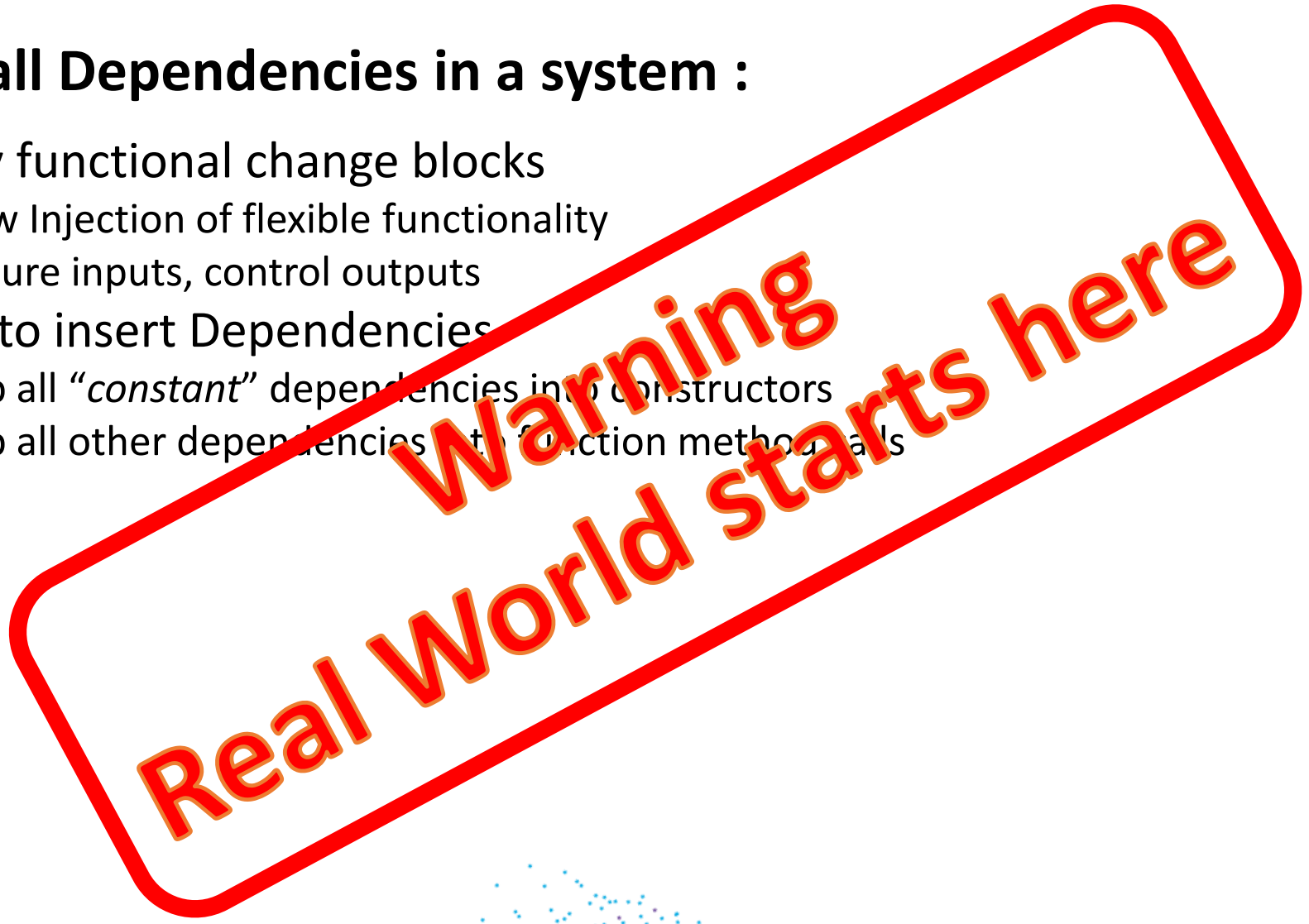
Types of Dependency Injection :

- ~~Setter Dependency Injection~~
- Method Injection
- Constructor Injection

Conceptual Dependency Injection

Control all Dependencies in a system :

- Identify functional change blocks
  - ❑ Allow Injection of flexible functionality
  - ❑ Capture inputs, control outputs
- Where to insert Dependencies
  - ❑ Drop all "*constant*" dependencies into constructors
  - ❑ Drop all other dependencies into function methods



Applied Dependency Injection

Dependency Injection road blocks :

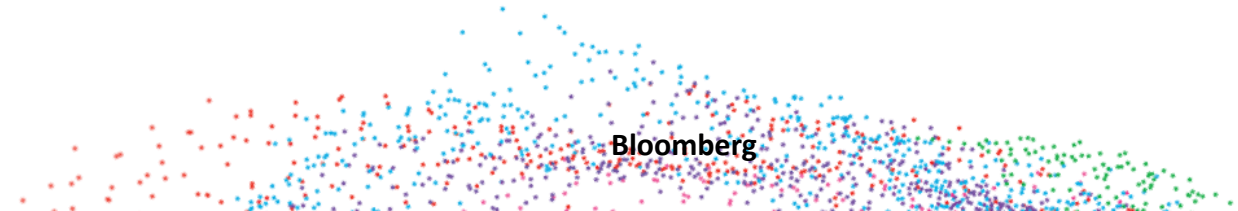
- Objects full creation hidden inside functions/classes
  - ❑ No handle to inject new functionality
  - ❑ Default class constructors initialized via Singletons/Globals

Dependency Injection Hazards

Object construction isolated inside functions

```
Class Handler {
    bool processA(Data& data, ...) {
      // ...
      Processor proc(<fixed args>);
      // ...
      return proc.apply(data);
    }

    bool processB(Data& data, ...) {
      // ...
      Processor& proc = ProcessorSingleton::instance->getProcessor(proc_tag);
      // ...
      return proc.apply(...);
    }
};
```



Applied Dependency Injection

Dependency Injection road blocks :

- Objects full creation hidden inside functions/classes
  - ❑ No handle to inject new functionality
  - ❑ Default class constructors initialized via Singletons/Globals
- Reaching through multiple objects
  - ❑ Long chains of mock classes needed as boilerplate
  - ❑ Breaks the principle of least knowledge

Dependency Injection Hazards

Reaching through multiple objects

```
void Processor::buildQuoteNZFlag(const Side& side) {
  // ...
  const Exch::TickHelper& hp = updater_.processingContext().exchanges().get(side.exchangeNumber()).legacyTickHelper();
  // ...
}
```

Law of Demeter : Only talk to your immediate friends

Applied Dependency Injection

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  - ❑ Breaks the principle of least knowledge
- Having too many dependencies in a class / functional block
  - ❑ Impractical to pass large number of Dependencies in constructor / function method

Refactoring for DI

```
bool execute(DB&, Com&, FileLdr&, Calc&, string, double, string, Cache&, const Data&, ...)
{
  // ...
}
```

Refactoring for DI

```
struct Bucket {
  DB& db_;
  Com& com_;
  FileLdr& ldr_;
  Calc calc_;
  string filename_;
  double multiplier_;
  string mode_;
  Cache& cache_;
  const Data& data_;
  // ...
};
```

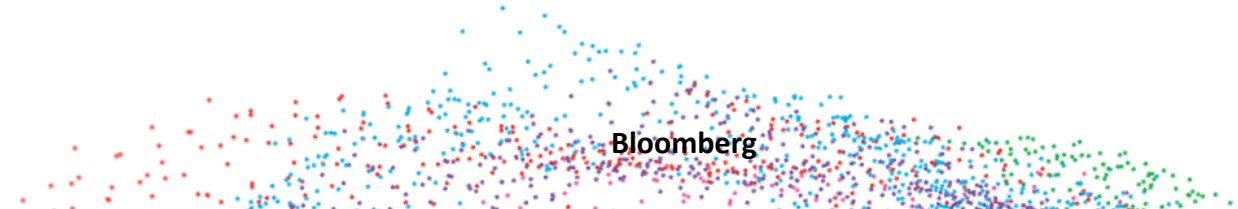
NOPE

Note :

- Unstructured bucket just moves the problem elsewhere
- What parts of a God bucket are used by a function

nb : Can work for coupled data of simple types

```
bool execute(Bucket& bucket)
{
  // ...
}
```



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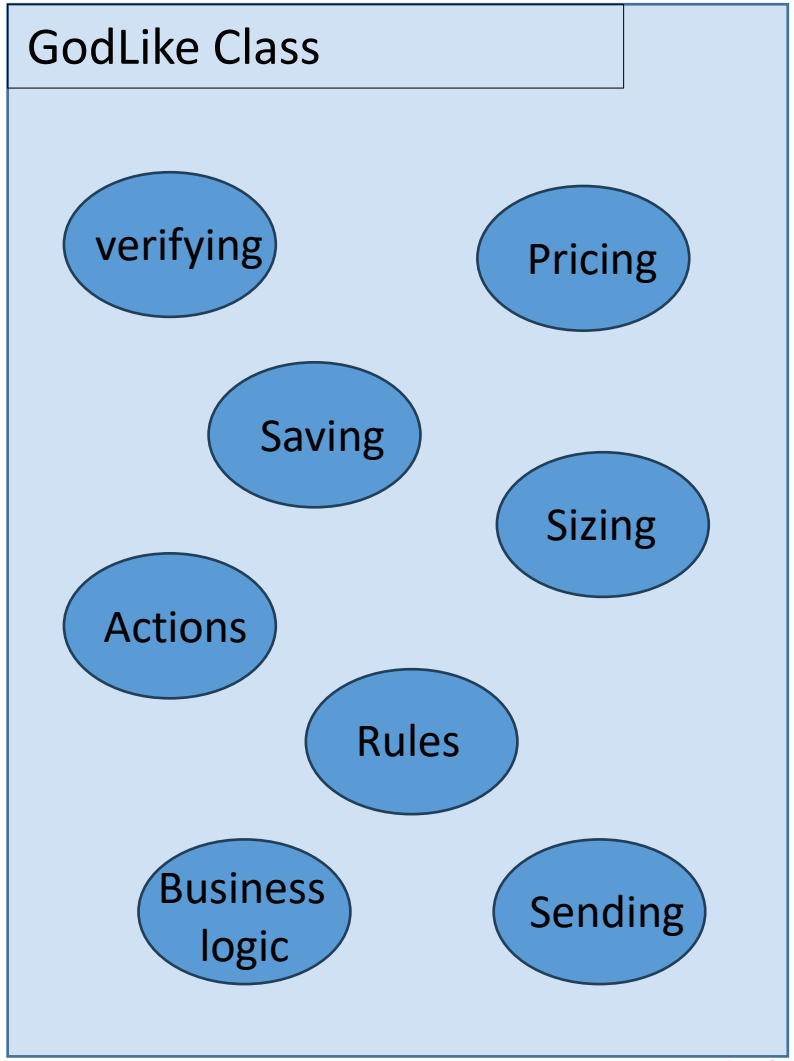
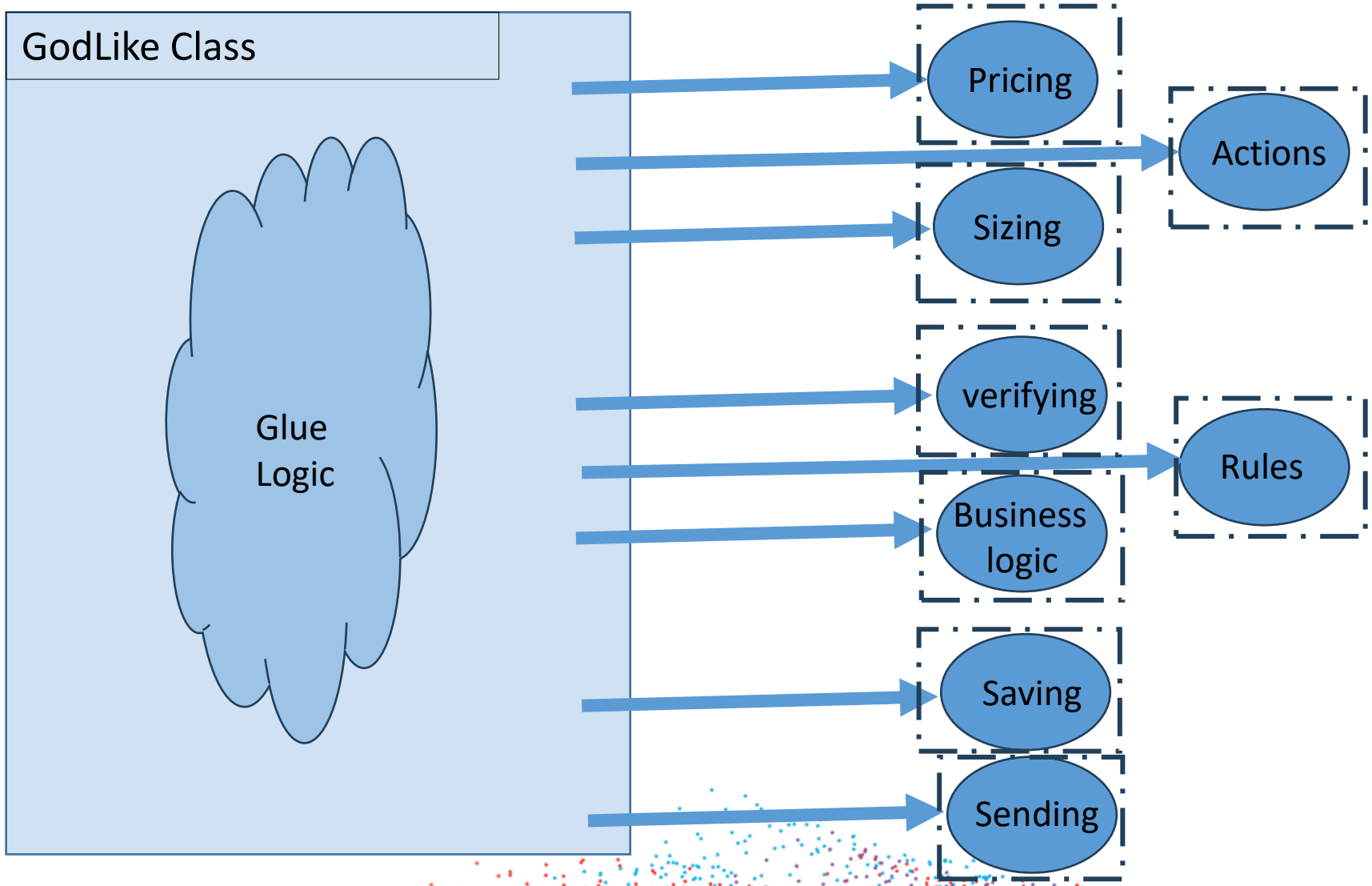
  - ❑ God Classes doing too many things
  - ❑ Many dependencies too numerous to inject

Refactoring for DI

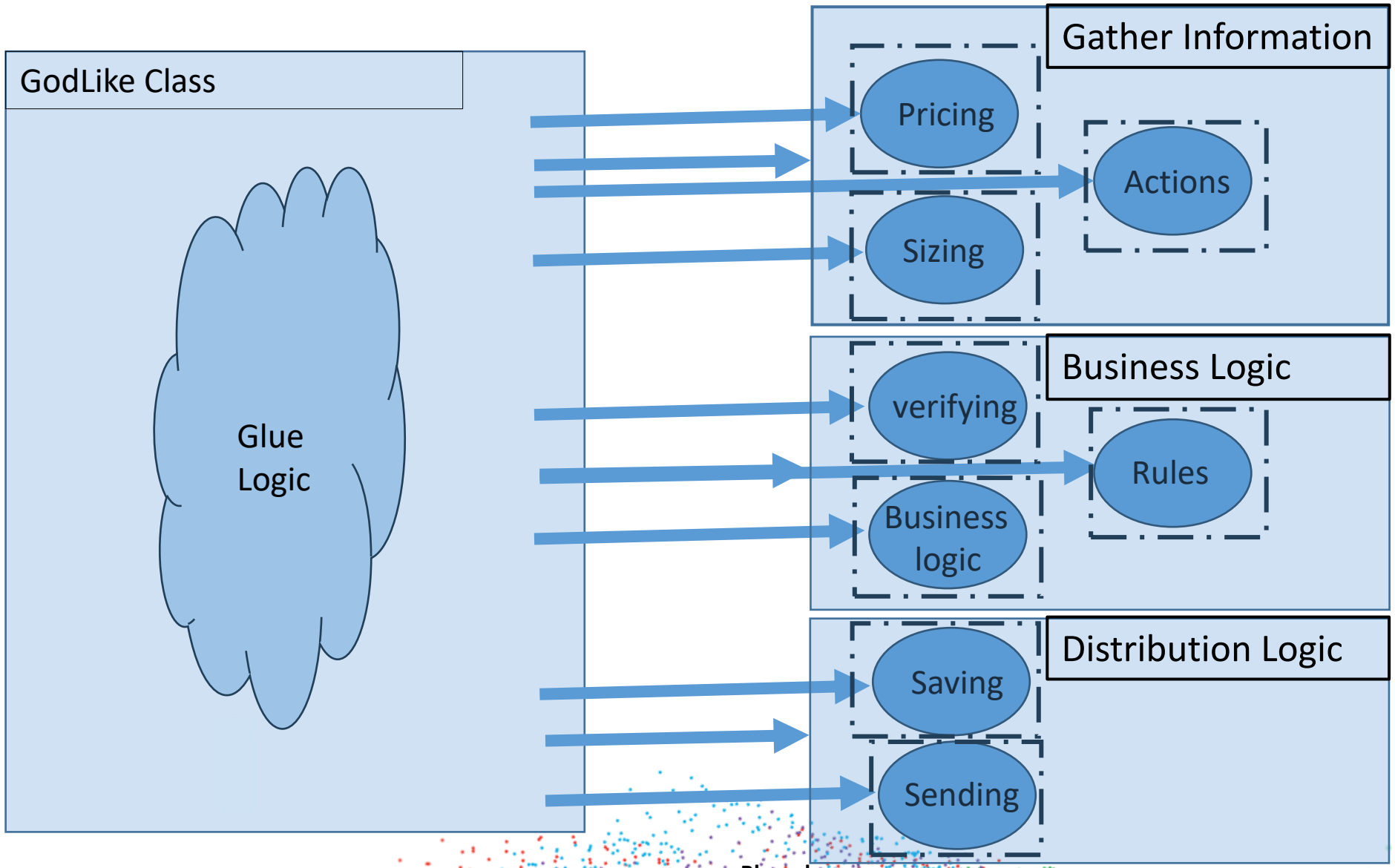


Refactoring for DI



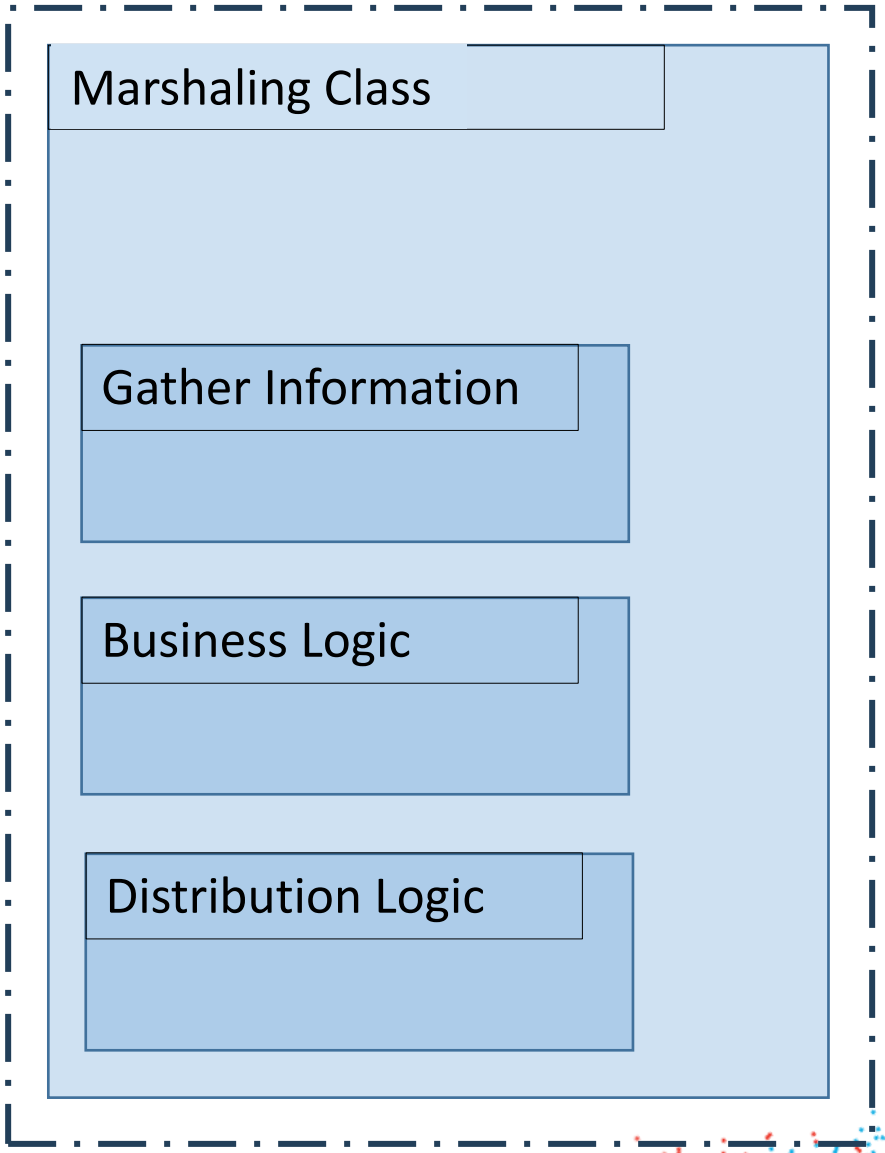
- ✓ Encapsulated functionality
- ✓ Unit testing
- ✓ Prelude to DI

Refactoring for DI

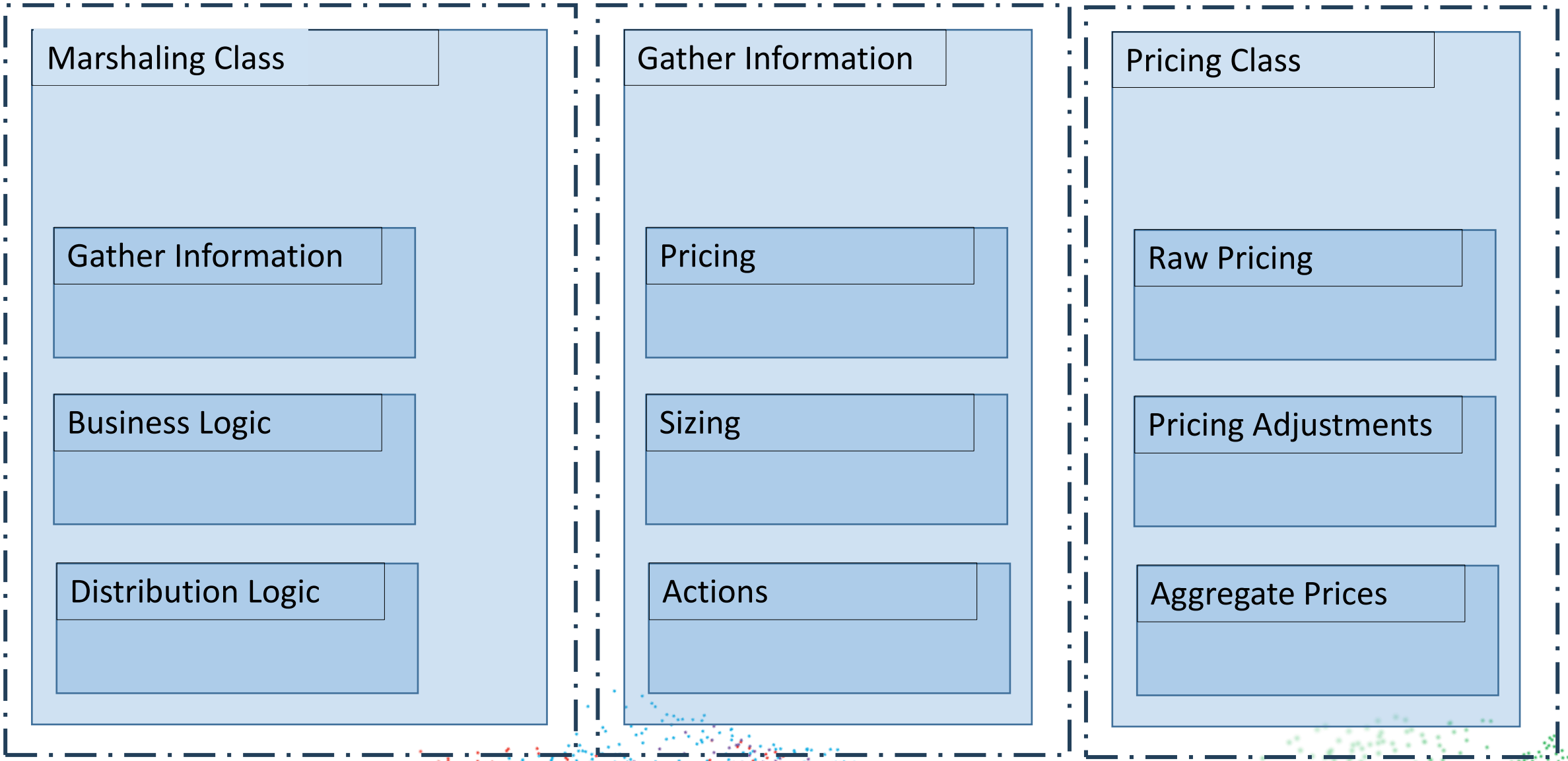


- ✓ Unit testing
- ✓ DI

Refactoring for DI



Refactoring for DI



Applied Dependency Injection

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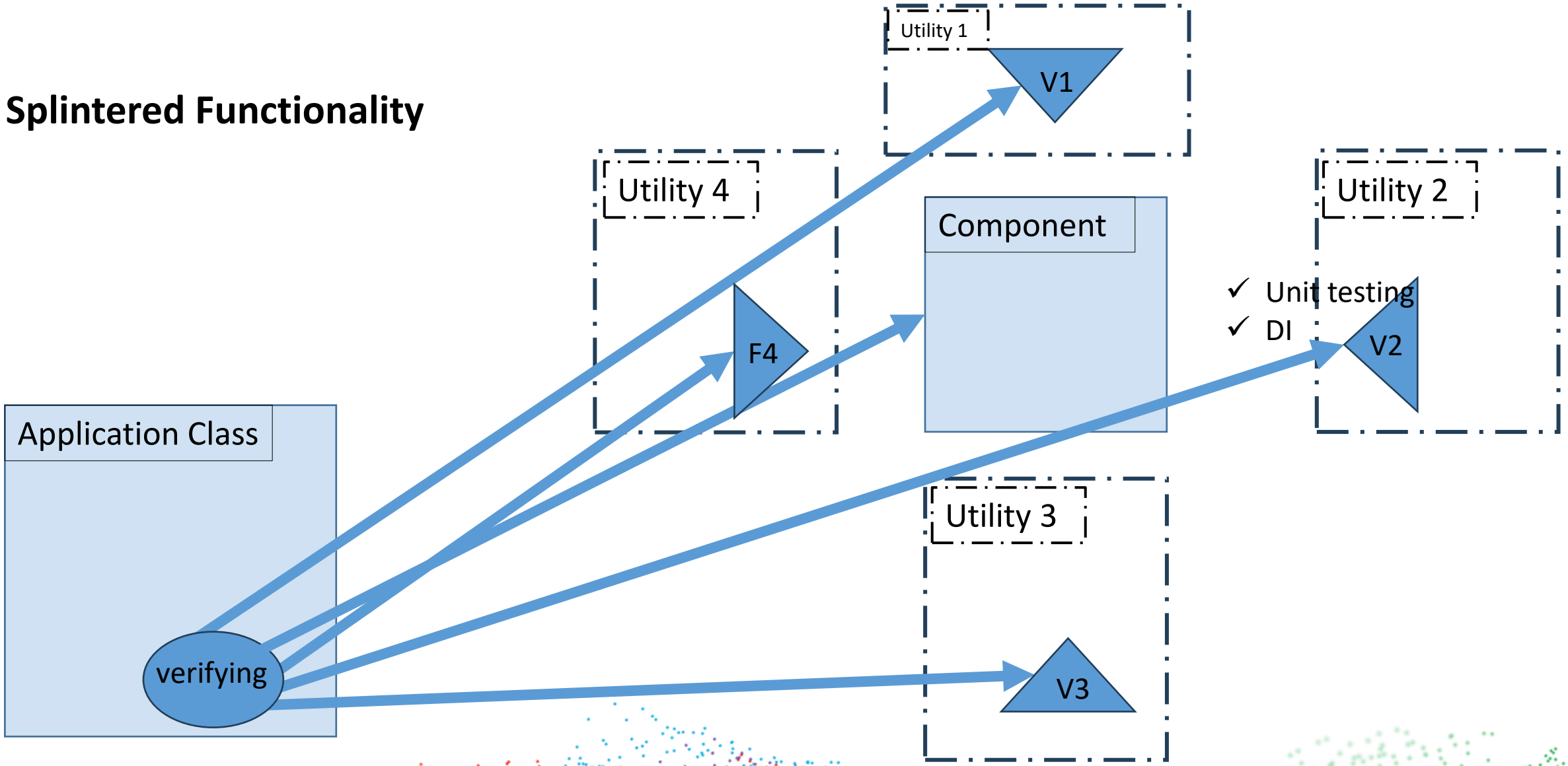
- Classes (hierarchies) packed with huge chunks of functionality
  - ❑ God Classes doing too many things
  - ❑ Many dependencies to numerous to inject
- Functionality splintered and spread throughout the codebase
  - ❑ Fragmented throughout the inheritance chain
  - ❑ Duplicated throughout the codebase
  - ❑ Blended into general utility classes

Refactoring for DI

Splintered Functionality



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Applied Dependency Injection

Dependency Injection highway express :

- Object creation done outside the logic of functions
  - ❑ Pass in Dependencies directly
  - ❑ Pass in Dependency suppliers
- Invoke methods on immediate objects
  - ❑ Avoid invoking methods on an object returned by other methods
- Refactor God classes
  - ❑ Functionality clustered and pushed into tiered abstraction layers
  - ❑ Lessen dependencies
- Refactor fragmented functionality
  - ❑ Cluster splintered functionality together
  - ❑ Lessen dependencies

Legacy Code DI

Legacy Code : Code that is working in Production for real users

Harder to apply Dependency Injection after code is released in Production

- Code not as malleable / External dependencies
- Large scale complex changes are
  - Riskier
  - Take substantial time
- Preference for Phased/localized changes

Need Tools & Tricks to implement Dependency Injection

DI for immutable APIs

Problem : API is used far and wide and so interface cannot be changed

DI for immutable APIs

Method dependency Injection

```
bool process (int key, const std::string&, CalcDep& calc) {defaultCalc) {
  // ...
  calc.estimate(...);
  // ...
};

// Forwarding function - deprecated
bool process (int key, const std::string& index) {
  process (key, index, defaultCalc);
};
```

Injection

Default Injection

DI for immutable APIs

Constructor dependency Injection

```
class DataProcessor {
  DataProcessor (int key, const std::string& index, CalcDep& calc = defaultCalc);
  // ...
};
```

DI for immutable APIs

Constructor dependency Injection

```
class DataProcessor {
  DataProcessor (int key, const std::string& index, CalcDep& calc);

  // Delegating constructor – deprecated
  DataProcessor (int key, const std::string& index) : DataProcessor (key, index, defaultCalc){};

  // ...
};
```

DI for immutable APIs

Problem : API is used far and wide and so interface cannot be changed

Solution : Transparent Dependency Injection using

- Default arguments
- Delegating
  - ❑Functions
  - ❑Constructors

DI for encapsulated functions

Encapsulated functionality : No internal side effects - outside of returned values

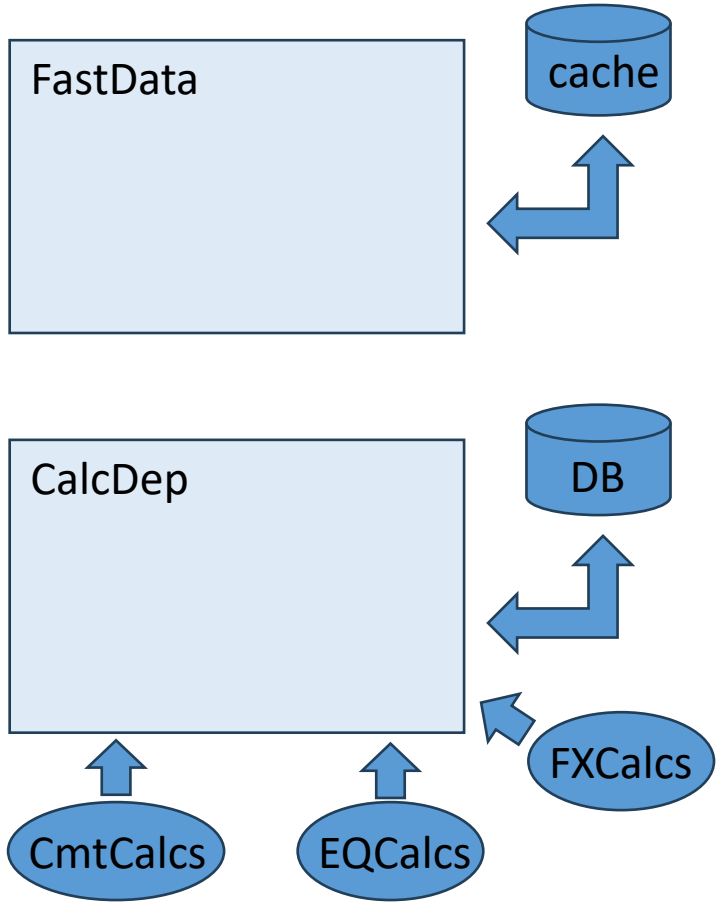
❑Not using hidden external dependencies.

DI for encapsulated functions

Problem : DI for Encapsulated functionality

```
Result compute(const FastData& data,
    const CalcDep& calc) {
```

```
struct MockCalcDep : public CalcDep {
  MOCK_METHOD(bool, fxcalc,  (...), (override));
  MOCK_METHOD(bool, eqcalc, (...), (override));
  // ...
};
struct MockFastData : public CalcFastData {
  MOCK_METHOD(bool, getData,  (...), (override));
  MOCK_METHOD(bool, prime, (...), (override));
  // ...
};
```



DI for encapsulated functions

Problem : Encapsulated functionality, no internal side effects - outside of returned values

- ❑Not using hidden external dependencies.

Solution : Mock classes passed in as parameters

DI for lazy object construction

Problem : Lazy initialization

- ❑Not able to pass in a constructed object

Phasing DI into Legacy Codebase

```
class Security {
:public
  Security(…, const std::string& index_name)
    : index_name_(index_name){};
  void apply(const ActionX& action)  {
    ensureLoaded();
     …
  }
:private
  void ensureLoaded() {
    if(!db_helper_)
      db_helper_ = createDbHelper(index_name_);
  }
  const std::string index_name_;
  std::unique_ptr<DBHelper> db_helper_;
};
```

Lazy Injection

Dependency

Phasing DI into Legacy Codebase

```
class Security {
:public
  Security(…, const std::string& index_name)
    : index_name_(index_name), db_helper_(createDbHelper(index_name_)){};
  void apply(const ActionX& action)  {
    ensureLoaded();
    …
  }
:private
  void ensureLoaded() {
    if(!db_helper_)
      db_helper_ = createDbHelper(index_name_);
  }
  const std::string index_name_;
  std::unique_ptr<DBHelper> db_helper_;
};
```

NOT LAZY

Injection

Dependency

Phasing DI into Legacy Codebase

```
class Security {
:public
  Security(…, const std::string& index_name)
    : index_name_(index_name){};
  void apply(const ActionX& action)  {
     ensureLoaded();
     …
  }
  bool setDBHelper(std::unique_ptr<DBHelper> dbh)
     { if(!db_helper_) db_helper_=dbh; …}
:private
  void ensureLoaded() {
     if(!db_helper_)
        db_helper_ = createDbHelper(index_name_);
  }
  std::unique_ptr<DBHelper> db_helper_;
};
```

Setter Injection

Dependency

Phasing DI into Legacy Codebase

```
class Security {
:public
 Security(…, const std::string& index_name)
  : index_name_(index_name){};
 void apply(const ActionX& action)  {
  ensureLoaded();
   …
 }
:private
 void ensureLoaded() {
  if(!db_helper_)
    db_helper_ = createDbHelper(index_name_);
 }

 std::unique_ptr<DBHelper> db_helper_;
};
```

```
using ProvideDBHelper = std::function<
 std::unique_ptr<DBHelper>(const std::string&) >;
```

Injection

Dependency

Phasing DI into Legacy Codebase

```
class Security {
:public
  Security(..., const std::string& index_name,
    ProvideDBHelper provide_dbhelper = createDbHelper)
    : index_name_(index_name),
      provide_dbhelper_(provide_dbhelper){};
  void apply(const ActionX& action)  {
     ensureLoaded();
     …
  }
:private
  void ensureLoaded() {
     if(!db_helper_)
       db_helper_ = provideDbHelper(index_name_);
  }
  ProvideDBHelper provide_dbhelper_;
  std::unique_ptr<DBHelper> db_helper_;
};
```

```
using ProvideDBHelper = std::function<
 std::unique_ptr<DBHelper>(const std::string&) >;
```

Provider Injection

Injection

Dependency Provider

Dependency Injection Snags

Problem : Dependency injection unexpected snags

Dependency Injection Snags

Problem : Templated member functions *cannot* be *virtual*

```
class Header {
public:
  virtual double getDividend(double rate) const;
  virtual void setModel(const ModelTag&, int modelID);

  template<typename T>
  TypeNum isType(const T&) const;
  virtual TypeNum Handler::isType(const string&) const;

 // …
};
```

```
template<typename T>
TypeNum Header::isType(const T& t) const{
  //...
}

template<>
TypeNum Header::isType(const string& str) const{
  //...
}
```

```
class MockHeader : public Header {
   MOCK_METHOD(double, getDividend, (double), (override, const));
   MOCK_METHOD(void, setModel, (const ModelTag&, int) , (override));
   MOCK_METHOD(void, isType, (const string &) , (override));
   // ???
};
```

Dependency Injection Snags

Problem : Templated member functions *cannot* be *virtual*

```
auto real_typenum = [](const Calc& calc, int val)
  { return calc.isType(val); };

auto test_typenum = [](const Calc&, int)
  { return TypeNum::A; }

class Processor {
public :
  using istype_fn = std::function<TypeNum(const Calc&, int)>;
  Processor(is_type_fn istype=real_typenum): istype_(istype)
    { //... }

  void apply(){
    //...
    string val = ...;
    Calc calc(...);
    TypeNum typenum = istype_(calc,val);
    //...
  };
  istype_fn istype_;
};
```

Injection

Testing

Dependency

Dependency Injection Snags

Problem : Templated member functions *cannot* be *virtual*

But Wait

You did’nt solve the problem

Dependency Injection Snags

Problem : Templated member functions *cannot* be *virtual*

```
class Processor {
public :
   Processor(...) ;
   { //... }
   template<typename T, CalcEngineT CalcT>
   void apply(T& val, CalcT& calc) {
   //...

   TypeNum typenum = calc.isType(val);
   //...
  };

};
```

Injection

Testing

Dependency Injection Snags

Problem : Templated member functions *cannot* be *virtual*

```
class Header {
public:
  virtual double getDividend(double rate) const;
  virtual void setModel(const ModelTag&, int modelID);

  template<typename T>
  TypeNum isType(const T&) const;

 // …
};

class MockHeader : public Header {
    MOCK_METHOD(double, getDividend, (double), (override, const));
    MOCK_METHOD(void, setModel, (const ModelTag&, int) , (override));
    MOCK_METHOD(void, isType, (const string &) , (override));
    // ???
};
```

Dependency Injection Snags

Problem : Templated member functions *cannot* be *virtual*

```
class Header {
public:
  virtual double getDividend(double rate) const;
  virtual void setModel(const ModelTag&, int modelID);

  template<typename T>
  TypeNum isType(const T&) const;

 // …
};

class MockHeader {
    MOCK_METHOD(double, getDividend, (double), (override, const));
    MOCK_METHOD(void, setModel, (const ModelTag&, int) , (override));
    template<typename T>
    TypeNum isType(const T&) const;
};
```

Dependency Injection Snags

Dependency injection unexpected snag

- Templated Functions when using Inheritance
  - ❑Turn into regular function If template is fully specialized
  - ❑For limited types, add type erasure at point of call to template function
  - ❑Move from Inheritance DI to Template DI

Dependency Injection Myths

DI Myths :

- It’s simple
- Only for simplistic systems parts of real systems
- Overkill on smaller projects
- Only for testing
- Forget for now, Easy to add in later

Dependency Injection Myths

Dependency Injection Truths :

- Its hard, for real Production systems
- Properly factored code is ultimate KEY to Dependency Injection for anything not a toy example
- Give weight to *local* refactoring prior to DI and allow for the extra time
- Poorly formed code needs many tricks for DI
- Improves the flexibility/reusability – and so testability - of a system
- Better long term maintainability of code

Dependency Injection Revelation

Dependency Injection ultimately boils down to

- Lessening number of dependencies needing injection
  - Horizontal abstraction : Refactoring code into decoupled functional chunks
  - Vertical abstraction : Refactoring code into tiered layers

Other Engineering talks by yours truly :

Retiring The Singleton Pattern : Concrete Suggestions on What to Use Instead
Redesigning Legacy Systems : Keys to success
Managing External APIs in Enterprise Systems
Exceptionally Bad : The Story on the Misuse of Exceptions and How to Do Better (Exceptions in C++ : Better Design Through Analysis of Real World usage)

Godbolt listings

https://godbolt.org/z/M497dsfbT - Link time Dependency injection
https://godbolt.org/z/4hzPnWWcY - Lazy Initialization, no DI
https://godbolt.org/z/e4z58qKoe - Lazy Initialization, proper DI
https://godbolt.org/z/a9TTK9sWb - Inheritance problem with template
https://godbolt.org/z/rhMET79f8 - Inheritance problem with template fixed
https://godbolt.org/z/j6P81eM8Y- Inheritance DI
https://godbolt.org/z/5aro8dKTz - Inheritance Modern Mock
https://godbolt.org/z/6G7MEnT9o - template DI
https://godbolt.org/z/EszM1ahW5 - template DI with concepts
https://godbolt.org/z/b95os3r3M - burying templates in constructor only
https://godbolt.org/z/3x3h3Yze4 - Std:move_only_function example

Questions?

Bloomberg is still hiring

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