CMPT 373
Software Development Methods

Handling Erroneous Behavior

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Sources of Error

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  - Users (both ignorant & malign)

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- You should develop your software to respond appropriately to erroneous behavior
  - The challenge is knowing what to do & when

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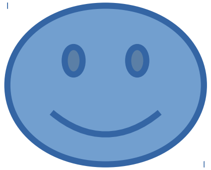

Mallory

Bob

Mallory, how much money would you like to transfer to Bob?

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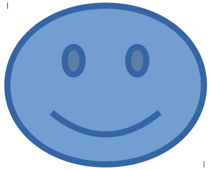

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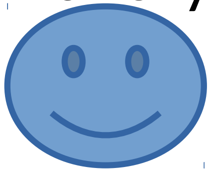

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Mallory, how much money would
you like to transfer to Bob?
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```

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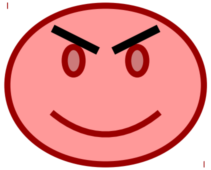

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you like to transfer to Bob?
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```
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```

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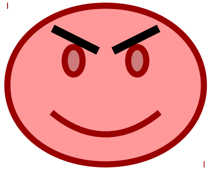

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```
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you like to transfer to Bob?
```

Ask yourself what should be allowable & enforce it

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  - If they can benefit from it, they will seek to
- Validate & sanitize all user input
  - Command line
  - Files
  - Databases
  - …

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- Prefer to provide feedback indicating the user error

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- Validate & sanitize all user input
  - Command line
  - Files
  - Databases
  - ...
- Prefer to provide feedback indicating the user error
- You can even use software hardening tools for better security (more in CMPT 473)

Handling Non-user Errors

- What if a function returns an unexpected value?
  - Can’t just print an error message for that function and ask it to return again….

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- Strategies for erroneous scenarios
  - Design them out of existence

Similar to what we did with ambiguous function arguments.

Handling Non-user Errors

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  - Return error codes & out arguments

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  - Design them out of existence
  - Assertions
  - Exceptions
  - Return error codes & out arguments

- All of these come with a cost and trade one form of complexity for another.

Defining Away Erroneous Behavior

- Use the type system to your advantage

```
computeForce(Mass{16g}, Acceleration{9.8mss})
```

Defining Away Erroneous Behavior

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- Generalize away corner cases

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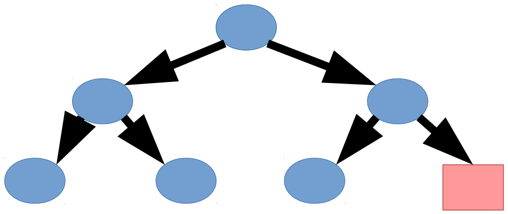
  - Implicitly – e.g. Null Object Pattern



Null Object Pattern
Create a subtype representing an object with no information.

Any getters/methods effectively perform no-ops.

Defining Away Erroneous Behavior

- Use the type system to your advantage
- Generalize away corner cases
  - Implicitly – e.g. Null Object Pattern
  - Explicitly – e.g. getChildren() vs getLeft() & getRight()

What are the trade offs?

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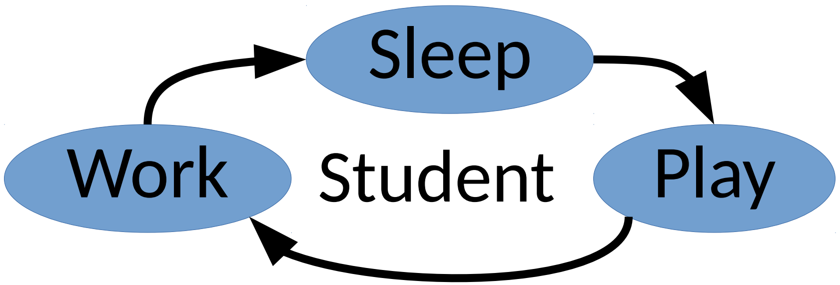

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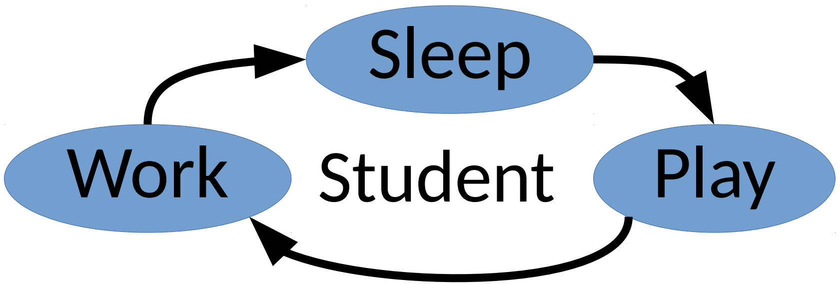


```
enum class CurrentState {
  SLEEP, PLAY, WORK
};
```

```
class Student {
  CurrentState state;
  uint64_t timeWorked;
};
```

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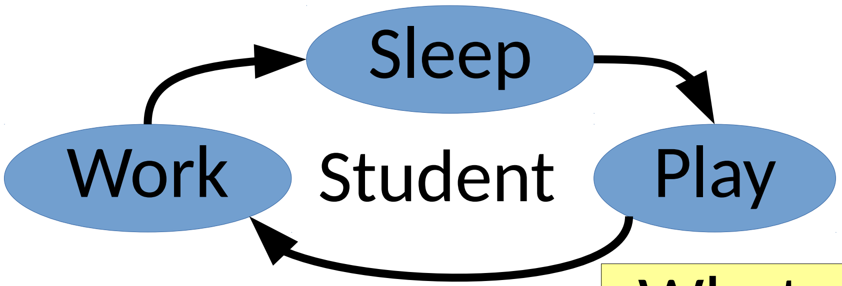


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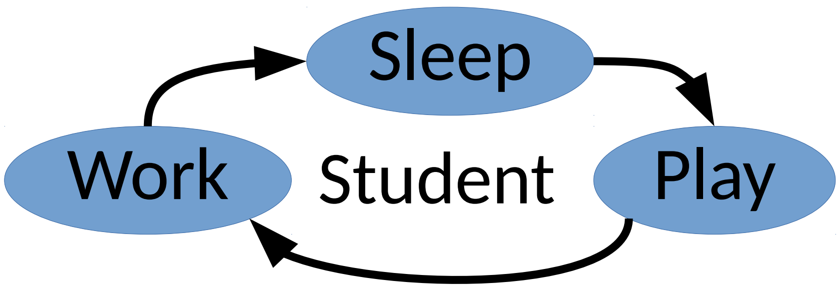
What can go wrong?

State Patterns & Sum Types

- How can we fix it?



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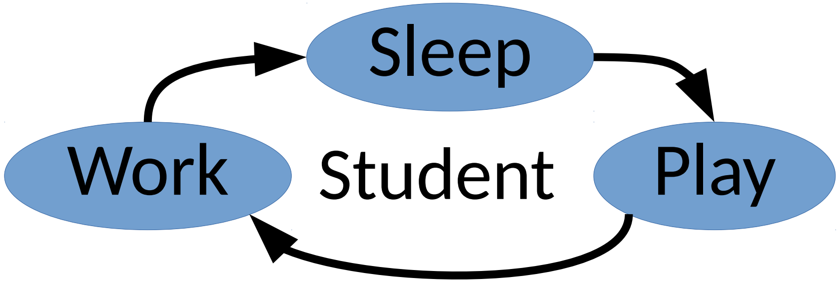


```
class CurrentState {
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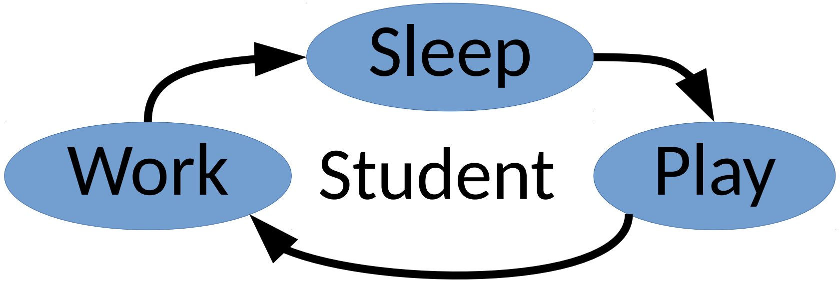


```
class CurrentState {
...
};
```

```
class Sleep
  : public CurrentState
{ };
```

```
class Work
  : public CurrentState {
  uint64_t timeWorked
};
```

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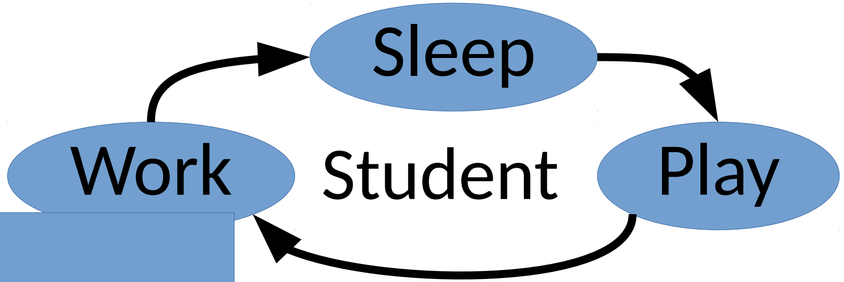


```
class Student {
  unique_ptr<CurrentState> state;
};
```

```
class CurrentState {
...
};
```

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  : public CurrentState
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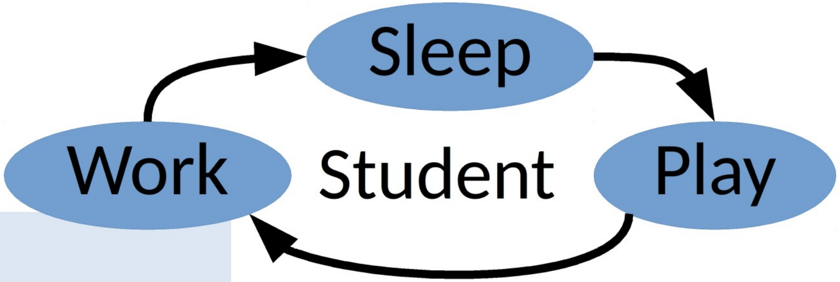


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```

```
class CurrentState {
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};
```

This is part of the ***state pattern***!

```
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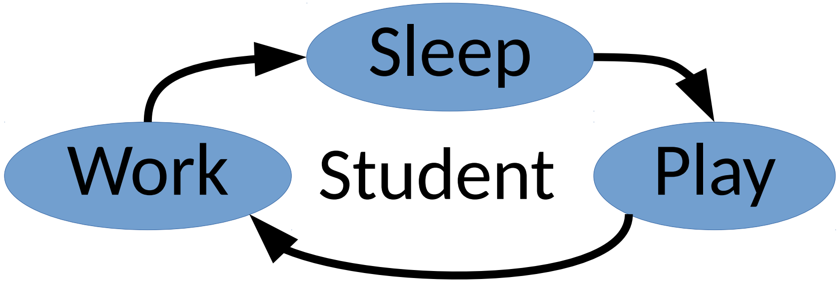


```
class Student {
  struct Sleep {};
  struct Play {};
  struct Work { uint64_t timeWorked; };

  std::variant<Sleep, Play, Work> currentState;
};
```

This uses ***sum types***!

State Patterns & Sum Types

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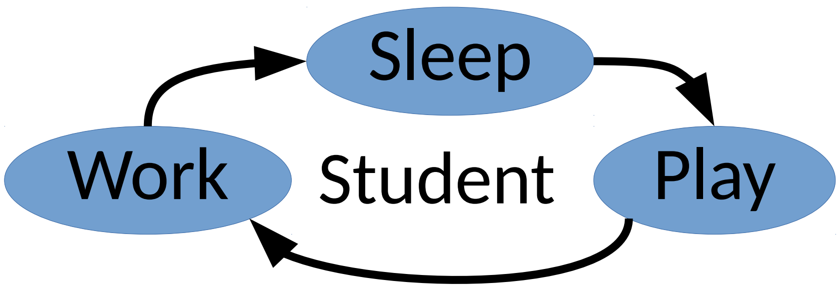


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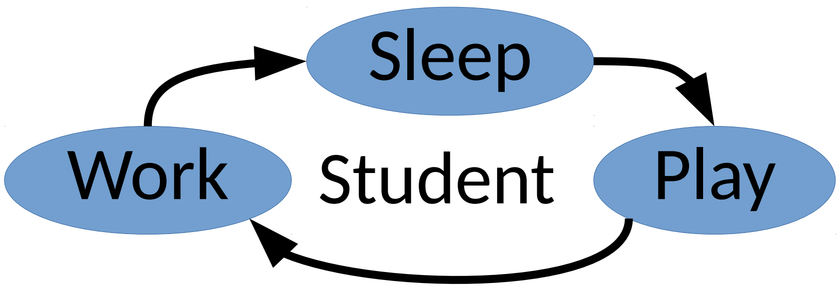


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```
std::optional<int>
divide(int numerator, int denominator);
```

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- Use the type system to your advantage

- Generalize away corner cases

- Make inconsistent state unrepresentable
  - State Pattern – richer state machines
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  - Phantom Types – Exploit parametric polymorphism

Phantom Types

```
double
distanceTraveled(double speed, double time) {
  return speed * time;
}
```

What can go wrong?

Phantom Types

```
double
distanceTraveled(double speed, double time) {
  return speed * time;
}
```

What can go wrong?

```
// Miles per hour * seconds?
... = distanceTraveled(3, 5);

d1 = ...; // Meters
d2 = ...; // Miles
... = d1 + d2; // Uh oh.
```

Phantom Types

- Parameterize your types by unique type names…

```
struct Meters {};
struct Miles {};
struct Seconds {};
struct Hours {};

template <typename T, typename U>
struct Speed { double speed; };

template <typename T>
struct Distance { double distance; };

template <typename T>
struct Time { double time; };
```

Phantom Types

- Consistent units are enforced via template arguments

```
template <typename T, typename U>
Distance<T>
distanceTraveled(Speed<T,U> speed, Time<U> time) {
  return {speed.speed * time.time};
}

template <typename T>
Distance<T>
operator+(Distance<T> d1, Distance<T> d2) {
  return d1.distance + d2.distance;
}
```

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Phantom Types

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distanceTraveled(Speed<Miles,Hours>{3}, Time<Seconds>{5});
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phantom.cpp:37:19: error: no matching function for call to 'distanceTraveled’
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d1 = distanceTraveled(Speed<Miles,Hours>{3}, Time<Hours>{5});
d2 = distanceTraveled(Speed<Meters,Seconds>{3}, Time<Seconds>{5});
d3 = d2 + d3;
```

phantom.cpp:41:30: error: invalid operands to binary expression
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What are the trade offs for using this technique?

Assertions

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  - What should be true when a function starts?
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```
#include <cassert>
constexpr char ascii[256] = ...

char getChar(int asciiCode) {
  assert(0 < asciiCode && asciiCode < 256
         && "ASCII code out of range.");
}
```

Assertions

- Assertions check the invariants of your program
  - What should be true when a function starts?
  - What should be true when a function ends?

- These are guaranteed bugs that should never happen in production!

- In general, better quality code has more assertions.

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  - Log the error & continue?
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- What should you do when an exception is thrown?
  - Nothing?
  - Try again?
  - Log the error & continue?
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- What should you pass to an exception when throwing?
  - Do you expect it to be re-tried?
  - Do you expect it to be logged?

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- As a developer, how do you respond to erroneous behavior?

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What if the cause occurred much earlier?

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Tracking behavior is crucial.
Real world software uses *logging*.

Logging

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LOG_IF(INFO, numUsers > 10)
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  << "numusers:" << numUsers;

CHECK_LT(index, size) << "Index out of bounds.";
CHECK_NOTNULL(ptr);
```

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Unexpected Situations

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  - Key branch points
  - Observation points

Unexpected Situations

Key Execution Points

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  Key Execution Points

- Logging *too little* or *too much* can be a problem
  - Might miss what you want
  - Might create a haystack for your needle
  - Might spend too many resources!

Logging Guidelines

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- Log logic that provides context for possible errors

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- Log all events needed for auditing
- Log logic that provides context for possible errors

Bear in mind, logging also comes at a price.
It is a *cross-cutting concern*.

Logging Guidelines

- Make your log easy to use
  - Machine parsable if possible (JSON logging!)

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- Make your log easy to use
  - Machine parsable if possible
  - What / When / Why / Where should be clearly captured

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- Many strategies for dealing with possible errors.
- Designing them away is preferred.
- All strategies have a cost.
- Logging is critical for dealing with real world code.