Complexity

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Laying a foundation

- Our goal for this lecture is pretty abstract.
  - We want to talk about goals for software
  - But we aren’t going to look at much code
Laying a foundation

- Our goal for this lecture is pretty abstract.
  - We want to talk about goals for software
  - But we aren’t going to look at much code

- Instead, I want to lay a foundation that you should keep in mind consistently as we consider code throughout the course.
Why do we care about software complexity?

- What even is software complexity?
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- What is the goal of a software engineer?
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  – ↓ maintenance costs
  – ↓ defect rates
  – ↓ legal liabilities
  – ↑ extensibility & reuse for new requirements
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  - ↓ defect rates
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  - ↑ extensibility & reuse for new requirements

- Our intuition may capture these, but software complexity is nuanced
Good engineers must exercise judgment

- Every problem has multiple solutions
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- Every problem has multiple solutions
- Good software engineering requires **evaluating** several forms of costs across many **different solutions** and **choosing** a cost effective solution
- Different solutions may be **functionally** equivalent but the **nonfunctional** attributes can determine what is appropriate for a specific problem
  - May differ radically in performance, maintainability, etc.
  - A good solution for one problem may be disastrous for another
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- A modern classic example is monolith vs microservices
The ravages of time

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- **But can’t our process include refactoring and redesign?**
  - In theory
  - In practice, to a limit
  - Much of the code in a bad design must be lived with & worked around
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- **Good judgment involves writing code that can cope with evolution**
The complexities we will not consider

- Complexity has many sources.
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  - Design and code is only one of them, but it will be our focus
  - Just as important (maybe more) are requirements
  - Clients often say they want A when they want B
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- **Requirements engineering & elicitation are more out of scope for us**
  - Supposedly CMPT 475 dives into those?
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- But I will still change requirements on you deliberately
So what *is* complexity?

- If we want to judge and assess it, it would be nice to define it but...
So what is complexity?

- If we want to judge and assess it, it would be nice to define it, but we don’t have a single good answer. It is openly researched & debated.
So what *is* complexity?

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- The goal is to capture the idea that software is hard to work with.
So what *is* complexity?

- If we want to judge and assess it, it would be nice to define it but... we don’t have a single good answer. It is openly researched & debated.
- The goal is to capture the idea that software is hard to work with.
- There are some classic definitions & even tools to check them.
Classic McCabe & Halstead measures

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- So count the *linearly independent paths* through a program.
  (each path has at least one unique edge)
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  - Idea: complexity may be about the number of independent behaviors
  - So count the **linearly independent paths** through a program.
    (each path has at least one unique edge)

```
if c1:
  ...(x)
else:
  ...(y)
if c2:
  ...(z)
```

- Consider the **control flow graph**

![Control flow graph diagram]
A classic measure available in tools is **McCabe** or *cyclomatic* complexity

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- Consider the *control flow graph*
- $M = \text{Edges} - \text{Nodes} + 2^{\text{Connected Components}}$
A classic measure available in tools is *McCabe* or *cyclomatic complexity*. 
- Idea: complexity may be about the number of independent behaviors.
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Consider the *control flow graph*:
- $M = 	ext{Edges} - 	ext{Nodes} + 2 \times \text{Connected Components}$
  - $M = 7 - 6 + 2 \times 1 = 3$
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- **Halstead complexity instead applies physics metaphors over**
  - Distinct # operators
  - Distinct # operands
  - Total # operators
  - Total # operands
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- These are easily automated & some companies use them. Are they good?
  - Well, not really
Classic McCabe & Halstead measures

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  - There is a bit more going on, but its utility is not considered cost effective
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- They also have *counterintuitive scenarios*

```java
void foo() {
    if (c1) { m } else { n }
    if (c2) { o } else { p }
    if (c3) { q } else { r }
    if (c4) { s } else { t }
    return;
}
```

\[ M = 16 - 13 + 2 \times 1 = 5 \]
Classic McCabe & Halstead measures

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```c
void foo()
{
  if (c1) { m } else { n }
  if (c2) { o } else { p }
  if (c3) { q } else { r }
  if (c4) { s } else { t }
  return;
}

M = 16 - 13 + 2*1 = 5

void mn()
{
  if (c1) { m } else { n }
}
void op()
{
  if (c1) { o } else { p }
}
void qr()
{
  if (c1) { q } else { r }
}
void st()
{
  if (c1) { s } else { t }
}

void foo()
{
  mn();
  op();
  qr();
  st();
  return;
}

M = 4 - 4 + 2*1 = 2
M = 4 - 4 + 2*1 = 2
M = 4 - 4 + 2*1 = 2
M = 4 - 4 + 2*1 = 2
M = 0 - 1 + 2*1 = 1
Classic McCabe & Halstead measures

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  - There is a bit more going on, but its utility is not considered cost effective
- They also have obvious *counterintuitive scenarios*
- *In practice just using whitespace & the shape of code*
  - is as effective
  - is more intuitive for people
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- In practice just using whitespace & the shape of code
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- This is still clearly limited in meaning, so it isn’t on the track we want
More philosophical definitions

- Being too specific may get in the way of defining a general concept
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- Instead, we can start to consider it by its intuitive effects
  - Complexity grows with size
  - It also grows as pieces of a system are connected or woven together
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[Watch “Simple Made Easy” for more on this perspective]
More philosophical definitions

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- Instead, we can start to consider it by its intuitive effects:
  - Complexity grows with size.
  - It also grows as pieces of a system are connected or woven together.
  - It grows as individual clarity is muddled by the bigger picture.
  
  [Watch “Simple Made Easy” for more on this perspective]

- We also have some general forms of complexity to consider:
  - Inherent (essential) complexity
  - Incidental (accidental) complexity
Refining these for code

- We can consider more specific symptoms for code [Ousterhout 2018]
Refining these for code

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- **Change Amplification**
  An apparently simple change requires modifying many locations

- **Cognitive Load**
  The developer needs to know a great deal in order to complete a task
Refining these for code

- **We can consider more specific symptoms for code** [Ousterhout 2018]
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    Potions of code to modify for a task may be hard to identify
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- We can then look for common causes to attack them
  - **Dependencies**
    Code cannot be understood in isolation because of relationships to other code.
  - **Obscurity**
    Important information about code is not obvious.
Signs of complexity

- These may present themselves in many ways
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  - Coupling
Signs of complexity

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- These may present themselves in many ways
  - Coupling
    - Content (accessing implementation of another component)
Signs of complexity

- These may present themselves in many ways
  - Coupling
    - Content
    - Common global data

```c
int global = ...
... = global
```

```c
global = ...
global = ...
... = global
```
Signs of complexity

- These may present themselves in many ways
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    - Content
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Signs of complexity

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Singletons have these constraints and worse.
Signs of complexity

- These may present themselves in many ways
  - Coupling
    - Content
    - Common global data
    - Subclassing

We will spend a day in the future on this.
Signs of complexity

- These may present themselves in many ways
  - Coupling
    - Content
    - Common global data
    - Subclassing
    - Temporal
Signs of complexity

- These may present themselves in many ways
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Cat cat = new Cat;
...
delete cat;
Signs of complexity

- These may present themselves in many ways
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Cat cat = new Cat;
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Process p;
p.doStep1();
p.doStep2();
p.doStep3();
Signs of complexity

- These may present themselves in many ways
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```
Cat cat = new Cat;
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delete cat;
```

```
Process p;
p.doStep1();
p.doStep2();
p.doStep3();
```

```
Process p;
p.foo();
p.bar();
p.baz();
```

This is more insidious!
Signs of complexity

- These may present themselves in many ways
  - Coupling
    - Content
    - Common global data
    - Subclassing
    - Temporal
    - Passing data to/from each other

```python
x = foo(1, 2)
def foo(a, b):
    ...
```
Signs of complexity

- These may present themselves in many ways
  - Coupling
    - Content
    - Common global data
    - Subclassing
    - Temporal
    - Passing data to/from each other
    - Independence
Signs of complexity

- These may present themselves in many ways
  - Coupling
  - Fan in vs fan out
Signs of complexity

These may present themselves in many ways

- Coupling
- Fan in vs fan out

Do you agree? Why?
Signs of complexity

- These may present themselves in many ways
  - Coupling
  - Fan in vs fan out
  - Layers & stratification

& a consistent, self contained view per level
Signs of complexity

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What impact does this have on invariants & types?
Signs of complexity

- These may present themselves in many ways
  - Coupling
  - Fan in vs fan out
  - Layers & stratification
  - Cohesion
Signs of complexity

- These may present themselves in many ways
  - Coupling
  - Fan in vs fan out
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  - Cohesion

- These are only some of the signals. In fact you can analyze your workflow to search for other signs!
(Some) ways to seek out complexity [Tornhill 2015]

- Analyzing your version control logs
  - Which files tend to change together?
  - Which files change frequently?
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- **Whitespace analysis & visual complexity**
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- Whitespace analysis & visual complexity
- Visualizing static coupling to assess potential risk
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- Whitespace analysis & visual complexity

- Visualizing static coupling to assess potential risk

- More guidance can be found in “Your Code as a Crime Scene”
Technical Debt

- Sometimes it may be worth allowing complexity temporarily in order to provide more value along another dimension
  - Perhaps it is to enable progress and exploration before refinement
  - Perhaps efficiency requirements are not well understood yet
  - ...
Technical Debt

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- Just like financial debt, it can be a useful tool, but the longer it goes unpaid, the greater the damages can be
  - And sometimes you may have unintended debts!
  - Teams that deliberately manage it may become 50% faster. [Gartner]
Where we will go

- Much of this semester will involve applying programming skills to explore these issues
  - We presented things abstractly here, but we will talk about concrete code.
  - You must be comfortable with concrete code.
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Where we will go

- Much of this semester will involve applying programming skills to explore these issues
  - We presented things abstractly here, but we will talk about concrete code.
  - You must be comfortable with concrete code.
- You will end up making trade offs and having regret
- *Regret is part of the point. It indicates that you learned something along the way.*
Summary

- You should have an intuition about *classic* & *modern* notions of complexity
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- You should understand the high level challenges with complexity that we will be trying to address going forward.
Summary

- You should have an intuition about *classic* & *modern* notions of complexity
- You should understand the high level challenges with complexity that we will be trying to address going forward
- You should understand that software engineering will involve *judgments* about trade offs and how to balance such objectives over time