Software Process

The Struggle to Manage Complexity: Waterfaull to Agile Process

The Invention of Software Process

- The Problem: Massive Project Failures in the 1960s
- The Cause of the Problem: Software systems became increasingly **large**, **complex**, and difficult to **manage**.

Software engineers began to recognize the growing challenges of managing software complexity.

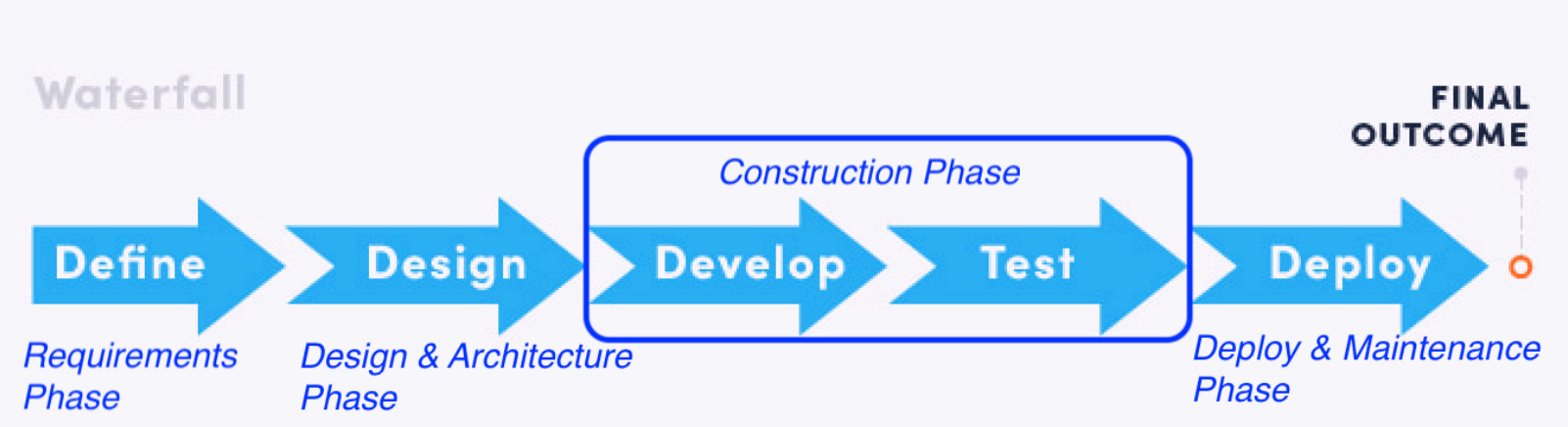
- Problems included missed deadlines, cost overruns, unreliable systems, and maintenance nightmares.
- This led to the first NATO Software Engineering Conference (1968).

Waterfall Process Model

- The Proposed Solution: Waterfall Model
- The Idea: Hardware Engineering
- By: Winston W. Royce, who described it in his 1970 paper titled "Managing the Development of Large Software Systems."

Manufacturing had clear phases (design → prototype → production), why not software?

- The Idea: In this model, we (1) define, (2) design, (3) develop (and test), and (4) test software.



SE Rules Applied - Process

- Divide and Conquer
- SRP (Single Responsibility Principle)
- Only Fools Rush In: We don't construct unless we know what to construct: Requirements and Architecture/Design are required to know what to construct.

What else?

The Attraction (Success) of the Waterfall Model

The Waterfall model appeared attractive because it promised **structure and control** through:

- Clear phases (Requirements → Design → Implementation → Testing → Maintenance)
- Detailed documentation at each stage
- Management checkpoints and approvals
- Predictable timelines and budgets

Even though the Waterfall model was **widely used** from the 1970s through the early 2000s, it ultimately proved to be ineffective for most large and changing software projects.

We should notice that:

- Waterfall did succeed (and still now) in some contexts (e.g., military or safety-critical systems)
- It couldn't handle changing requirements or iterative feedback, which led to the rise of Agile methods in the 1990s–2000s.

Why the Waterfall Model Struggled to Manage Real-World Complexity?

1. Requirements Change

Linear Thinking ≠ Complex Reality

```
Waterfall Assumption:          Reality:
A → B → C → D                  A ↔ B
                               ↕   ↕
                               D ↔ C
```

By the time you finish a 2-year waterfall project, the world & requirements has changed!

2. "Big Bang" Integration

- Modules developed separately for months
- Integrated only at the end
- Result: **Integration Hell** - components don't work together
- Example: Team A's login module expects JSON, Team B's database returns XML

3. Late Testing = Expensive Disasters

- You don't test until the end, so you discover problems when it's most expensive to fix.

Cost Multiplier: **Compounding Errors**

Fix a bug in the requirements phase: $1
Fix a bug in the design phase: $10
Fix a bug in the coding phase: $100
Fix a bug in the testing phase: $1,000
Fix a bug after deployment: $10,000+

4. No Feedback Loops

```
Waterfall: Requirements → [BLACK BOX] → Final Product
```

- Complexity requires **continuous learning**
- Waterfall provides **no mechanism to learn and adapt**

The Fundamental Flaw of the Waterfall Model (The Confusion of complicated vs complex)

- Waterfall treats software like a **complicated** problem (like building a bridge) when it's actually a **complex** problem (like managing an ecosystem).
- Complex problems require iterative exploration, not upfront planning.

Software engineers learned it the hard way.

Complicated vs. Complex

The complicated: something that has many parts

- It can be challenging because of the number of components involved.
- It is ultimately knowable and can be figured out, often by experts using analysis, decomposition, or expertise.
- Complicated systems tend to have solutions that can be identified or engineered by breaking down the problem into manageable parts.

The complex: something inherently unpredictable and difficult to fully understand or control from changes

- Complexity arises from interdependencies, emergent behaviors, and dynamic interactions.
- It defies simple cause-and-effect reasoning and often reveals "unknown unknowns" only in hindsight.
- Complex systems demand adaptive, iterative, and holistic approaches—not rigid, linear processes.

Real Example of the Waterfall Model Failure

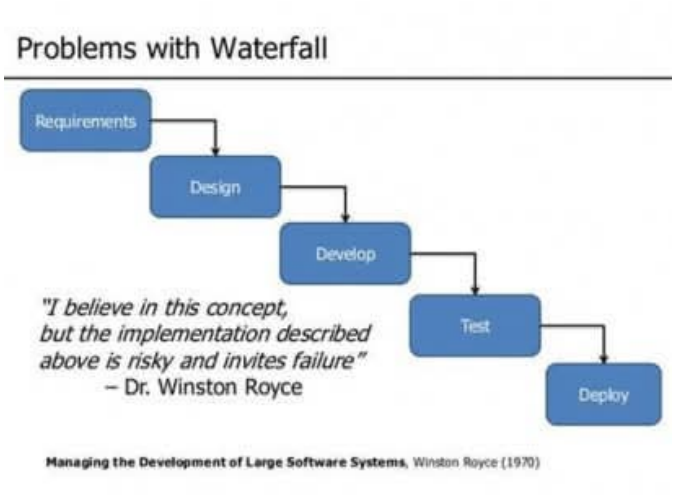
The FBI's Virtual Case File project (2000-2005):

- Cost: $170 million
- Result: Completely abandoned
- Why?: They followed waterfall, built everything, then discovered it didn't work and couldn't meet actual FBI agent needs

Perfect plan and implementation to get horrible results following the waterfall model

The Irony of the Waterfall Model

- Royce was actually critical of it.
- In his paper, Royce presented this sequential approach (requirements → design → implementation → testing → maintenance)



- Then, spent most of the paper explaining why this approach was **risky** and suggesting improvements including:
  - Iterative development
  - Prototyping
  - User involvement throughout the process

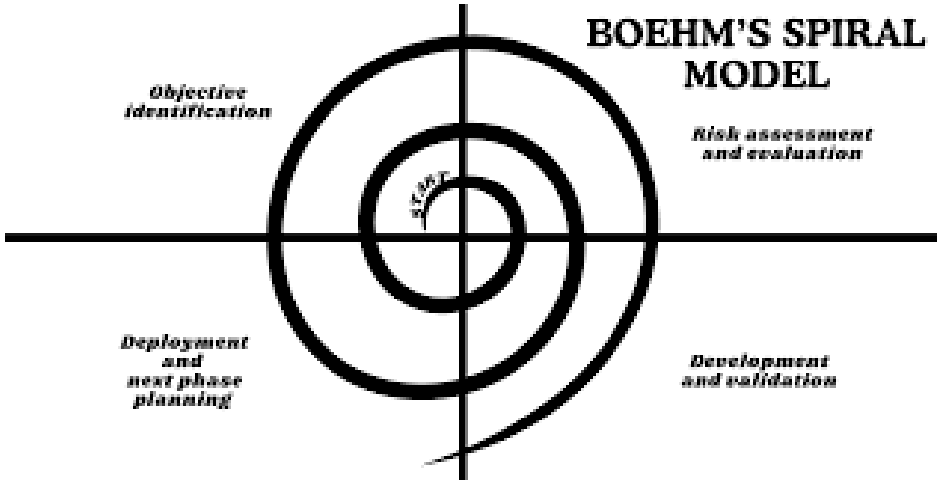
The Lessons Learned from the Waterfall Model

> Structure alone doesn't manage **complexity**—you need **adaptive** processes with fast feedback loops!

Now, we understand the goal is to `manage complexity`, not `complication`, but how?

The Spiral Model (1986)

- Barry Boehm proposed the **Spiral Model**, the first major alternative to the Waterfall approach.
- The Spiral Model emphasized (1) **iterative development** and (2) **continuous risk evaluation** at every stage.



- He managed risks continuously throughout each cycle.
- His model blended Waterfall's structure with iterative flexibility.

Versioning Reflects the Spiral Model

The version naming convention (e.g., DOS 3.1 → 3.2, Windows 10 → 11) illustrates Barry Boehm's **Spiral Model** principles:

- Each version marks a new iteration.
- Teams evaluate risks and improvements each cycle.
- Software evolves continuously, not in a single release.

The Problem: Spiral Was Better, But Still Not Enough

What Spiral Fixed:

✅ Risk management
✅ Iterative development
✅ Early prototyping

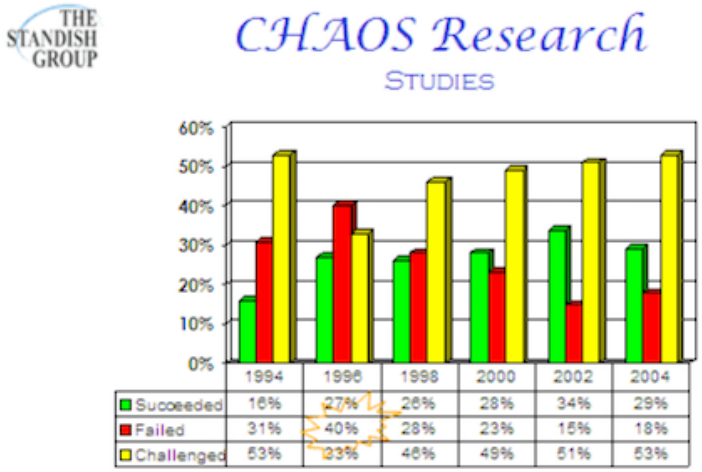
What Spiral Didn't Fix:

❌ Still heavy on documentation
❌ Still required extensive planning
❌ Still slow to respond to change
❌ Still process-heavy, not people-focused

The 1990s: Growing Frustration

Software Industry Problems:

1. Projects Still Failing



- Standish Group (1994)
  - Only 16% of projects succeeded
  - 53% were over budget/late
  - 31% were cancelled

2. Market Speed Changed
    - Internet boom demanded faster delivery
    - 6-month spirals too slow for web applications
3. Developer Burnout
    - Too much documentation
    - Too little coding
    - Rigid processes killed creativity

Why? What is missing?

The Missing Ingredient: People Over Process

Boehm focused on **RISK**

However, we need the model that would focus on **PEOPLE**.

```
Spiral Model:
  "How do we reduce technical risk?"

People-Focused Model:
  "How do we empower people to build
   what customers actually need?"
```

The Path to Agile: Key Milestones

1. Rapid Application Development (RAD) - 1991

- James Martin
- Focus: Build fast, iterate faster
- Introduced: Time-boxing (fixed deadlines)

2. Scrum - 1995

- Jeff Sutherland & Ken Schwaber
- Rugby metaphor: Self-organizing teams
- Introduced: Sprints, Daily standups

3. **Extreme Programming (XP) - 1996**
    - Kent Beck
    - Focus: Technical excellence
    - Introduced: Pair programming, TDD, Continuous Integration
4. **Feature-Driven Development - 1997**
    - Jeff De Luca with contributions from Peter Coad
    - Focus: Short iterations delivering features

February 2001: The Agile Manifesto

17 Software Developers met in Snowbird, Utah

Including:

- Kent Beck (XP)
- Jeff Sutherland (Scrum)
- Martin Fowler (Refactoring)
- Robert C. Martin (Uncle Bob)
- And 13 others

Mission: Find common ground between their methodologies


Manifesto for Agile Software Development
We are uncovering better ways of developing software by doing it and helping others do it. Through this work we have come to value:
Individuals and interactions over processes and tools
Working software over comprehensive documentation
Customer collaboration over contract negotiation
Responding to change over following a plan
That is, while there is value in the items on the right, we value the items on the left more.

Comparing the Models

Aspect	Spiral	Agile
Focus	Risk management	Customer value
Cycle Length	Months	Weeks (1-4)
Documentation	Heavy	Minimal (just enough)
Team Structure	Role-based	Self-organizing
Planning	Extensive upfront	Adaptive
Customer	Reviews iterations	Embedded in team

Key Philosophical Shift (From RISK to HUMAN)

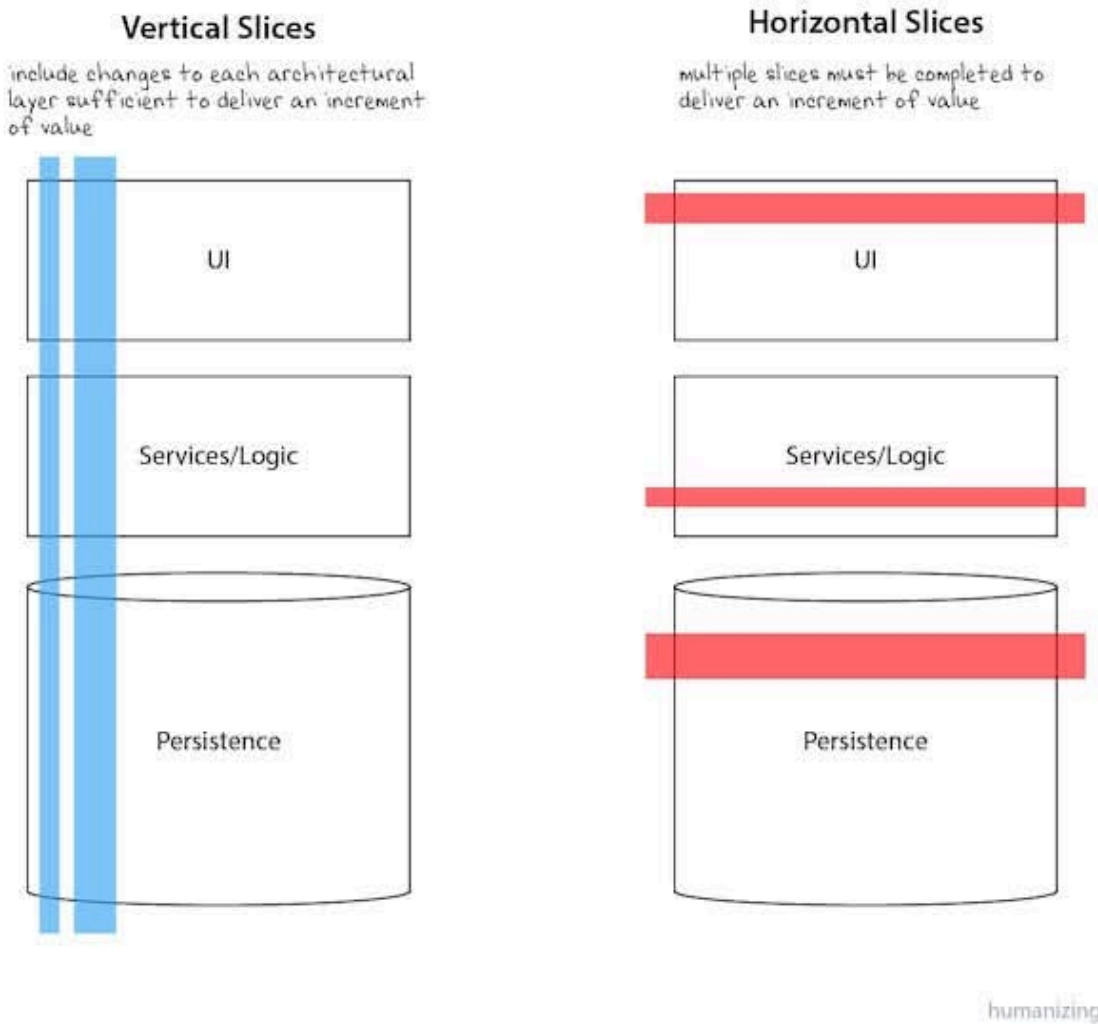
1. Spiral Model Mindset:

```
Plan → Analyze Risk → Build → Review → Replan
(Focus: "What could go wrong?")
```

2. Agile Mindset:

```
Collaborate → Build Small → Get Feedback → Adapt
(Focus: "What creates value?")
```

Veritcal Slice vs. Horizontal Slice



Example: Building an E-commerce Site

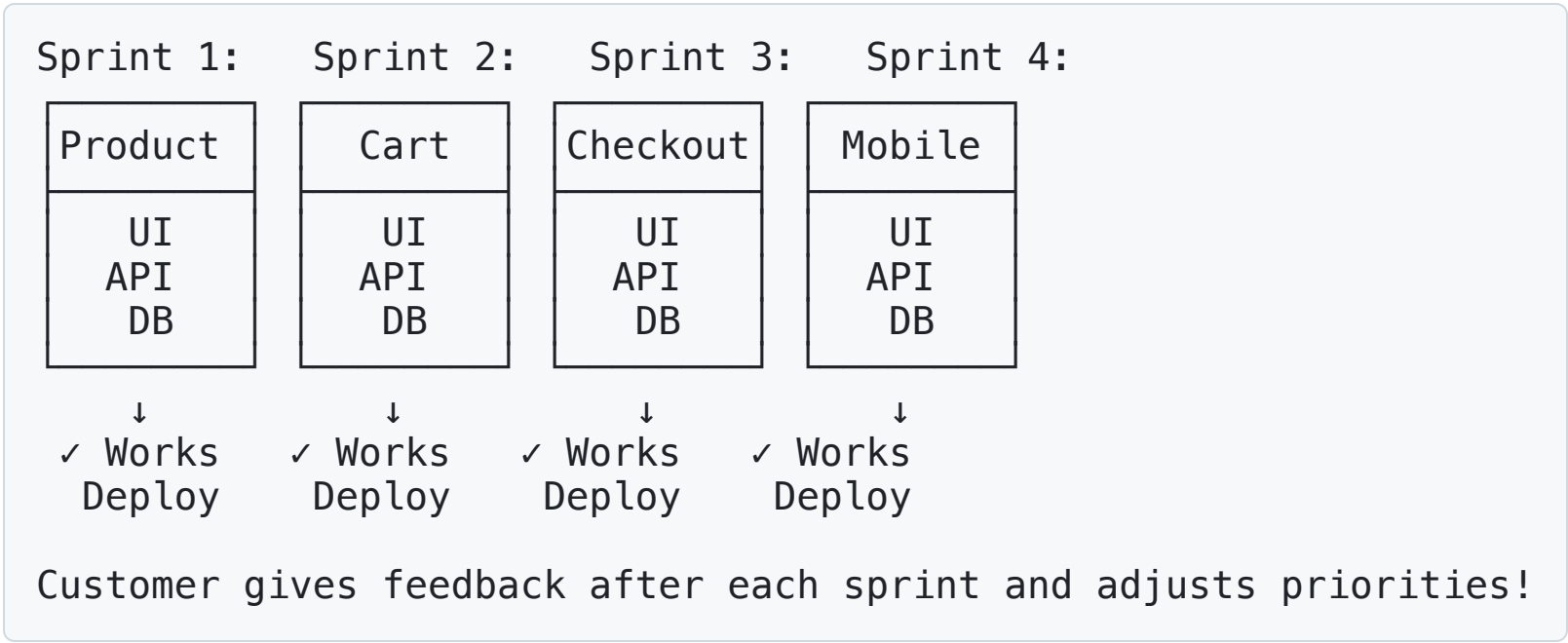
1. Spiral = Horizontal Slice (Layer-by-Layer)

```
Month 1–2: Plan everything
Month 3–5: Build all layers horizontally

      ┌──────────────────────────────────────┐
      │ Products │ Cart │ Checkout │ Mobile │ ← UI Layer
      ├──────────────────────────────────────┤
      │ Products │ Cart │ Checkout │ Mobile │ ← API Layer
      ├──────────────────────────────────────┤
      │ Products │ Cart │ Checkout │ Mobile │ ← DB Layer
      └──────────────────────────────────────┘
                  ↓
Month 6: Integration + Customer sees it first time
  – Customer: "This isn't what we wanted!"
  – 6 more months to fix
```

❌ **Problem**: Nothing works end-to-end until month 6. Late feedback. High risk.

2. Agile = Vertical Slice (Feature-by-Feature)



✅ **Benefit**: Working feature every 2 weeks. Early feedback. Low risk.

Key Differences:

	Spiral (Horizontal)	Agile (Vertical)
Build	All features, one layer at a time	One feature, all layers at once
First working feature	Month 6	Week 2
Customer feedback	After 6 months	Every 2 weeks
Risk	High (big bang integration)	Low (incremental)

Simple Analogy:

- **Horizontal**: Build foundation for entire house → frame entire house → finish entire house
    - *Can't use any room until everything is done*
- **Vertical**: Build complete kitchen → build complete bedroom → build complete bathroom
    - *Use the kitchen while building the bedroom!*

Why Agile Succeeded Where Spiral Couldn't

1. **Speed to Market**
   - Spiral: Months per iteration
   - Agile: Working software every 1-4 weeks
2. **Real Feedback**
   - Spiral: Prototypes and reviews
   - Agile: Real users with real software
3. **Adaptability**
   - Spiral: Change requires new spiral
   - Agile: Change every sprint

4. **Team Empowerment**
   - Spiral: Architects analyze risk, developers build
   - Agile: Self-organizing teams make decisions
5. **Less Waste**
   - Spiral: Extensive documentation and analysis
   - Agile: Just enough, just in time
6. **Continuous Delivery**
   - Spiral: Big releases after each spiral
   - Agile: Small releases continuously

The Technical Practices That Made Agile Possible

XP's Technical Innovations:

1. **Test-Driven Development (TDD)**

```
# Write test first
def test_shopping_cart():
    cart = ShoppingCart()
    cart.add_item("Book", 10.00)
    assert cart.total() == 10.00

# Then write code to pass the test
class ShoppingCart:
    def add_item(self, name, price):
        self.items.append((name, price))
```

2. **Continuous Integration (CI)**
    - Code integrated multiple times per day
    - Automated tests run on every commit
    - Problems found within minutes, not months
3. **Pair Programming**
    - Two developers, one computer
    - Continuous code review
    - Knowledge sharing
4. **Refactoring**
    - Constantly improve code structure
    - Enabled by automated tests