The Waterfall Model – What It Is Not and Has Never Been

May 18, 2012

Peter Hantos
Software Acquisition and Process Department
Software Engineering Subdivision

Prepared for:
Space and Missile Systems Center
Air Force Space Command
483 N. Aviation Blvd.
El Segundo, CA  90245-2808

Authorized by: Senior Vice President, Engineering and Technology Group

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The Aerospace Corporation

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Outline

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- Incremental Integration and Pair-wise Testing
- Scaling
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Motivation

- Your first reaction might be “Why are we talking about the waterfall? I thought that the Waterfall was dead”
  - Indeed, since the Waterfall model was published, the literature has been full with critiques and proposals for alternative processes, most recently Agile Development
- However, a substantial percentage of waterfall project failures can be attributed to lack of understanding of some fundamental issues, issues that are also present when modern methodologies are used
  - Ignoring such issues will lead to project failure, regardless of the methodology that is used
- Also, the waterfall (or, a “mini” waterfall) is still an essential building block of all the more complex life cycle models, such as incremental, evolutionary, spiral, or iterative incremental development (IID)
Parsing the Title-1: “Waterfall” is a metaphor
Parsing the Title-2: Model

• Definition of a model*
  – A model is always a reproduction of an original system
    • However, a model is an abstraction and does not reproduce all attributes of the original system
  – Models serve a certain purpose and they are to be used in a certain context

• What we are going to do
  – Start with the prevailing description of the Waterfall Model
  – Highlight the hidden abstractions of the model
  – Develop successively more complex descriptions to facilitate the understanding of underlying issues

All models are wrong. Some models are useful.
~~~ George Box

* [Stachowiak 1973]
The Canonical Waterfall Model

Legend
CDR - critical design review
PDR - product design review
SRR - software requirements review

* [Boehm 1981]
Model Characterization

- Scaling: **No**
  - Seems to depict a macro view of software development
- Depiction of feedback loops: **No**
- Depiction of concurrency: **No**
- Presence of other technical disciplines: **No**
  - The “product” is software only
Hidden Feedback Loops

- Having feedback loops is a matter of reality*
  - There are successive, small iteration feedback-loops between successive steps
  - The correction of defects discovered during the final test phases requires design specification changes or ultimately, requirements specification changes
  - The basic interpretation of the metaphor (one-directional flow) needs to be challenged

* Based on [Royce 1970]
Phase Overlap Added – the Sashimi Model*

- Overlap is suggested between phases
  - This overlap can reduce belated problem discovery
- However, in most cases this is not really concurrency but iteration
  - Correcting design while coding is essentially iteration
  - It was shown earlier that to deal with defects such small-scale iteration is inherently present in the Waterfall model

* Source: [McConnell 1996]. Note his slightly more up-to-date terminology.
What Does the Waterfall Life Cycle Really Look Like?

<table>
<thead>
<tr>
<th>PDR</th>
<th>CDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product design</td>
<td>Detailed design</td>
</tr>
<tr>
<td>Detailed design specification</td>
<td>Code and unit test</td>
</tr>
<tr>
<td>Code</td>
<td>Integration and test</td>
</tr>
<tr>
<td>Unit test</td>
<td>Design rework</td>
</tr>
<tr>
<td>Integration and test</td>
<td>Code</td>
</tr>
<tr>
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<tr>
<td>Integration and test</td>
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</tr>
<tr>
<td>Regression test</td>
<td>Regression test</td>
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</tbody>
</table>

- **Feedback loops’ impact on the life cycle**
  - Activities don’t neatly map into the life cycle phases anymore
  - Diagram does not even show the impact of failed integration and regression tests
  - Length of the “Integration and test” life cycle phase is becoming more uncertain
Selected Name Changes to Clarify the Model's Intent

- Some of the terminology in the original model is outdated or confusing
  - Changes reflect that in this version of the model software is the product
  - New phase and review names now clearly show that they relate to software
  - These clarifications are helpful if we need to place the model in an acquisition or a software-intensive system development context

* Note that in modern terminology “high-level design” is replaced with “architectural design” and the work product is Software Architecture Description (SAD)
"Hidden" Concurrency in the Waterfall Model

- Unit-level work represents independent and concurrent processes
  - This is where the waterfall is a truly fitting metaphor
  - The streams don't meet before hitting the pool at the bottom
- Note that SCDR positioning and content are ambiguous due to the fact that phase boundaries are now blurred
Incremental Integration and Pair-wise* Testing

- This strategy can reduce the problems stemming from belated problem discovery
  - In terms of the metaphor, note the intermediate pools in the picture
  - As a side-effect, phase boundaries are further blurred and the life cycle aspects of the model are less-and-less valid

* “Pairs” should not be taken literally; multiple units can be integrated as well
Scaling

- As it was discussed, the model seems to be a macro-model
  - However, the mentioned shortfalls are amplified if the process is indeed executed on the macro level
- Many of the problems can be dealt with if Incremental/Evolutionary strategies are used on the macro-level (including acquisition,) and Waterfall is applied only on lower levels
  - For example, the following strategy hierarchy can be implemented in a space system
    - Acquisition – Once-through (Equivalent of the Waterfall) or Evolutionary
    - System – Incremental Development involving segments
    - Segment – Incremental Development involving elements
    - Elements – Incremental Development involving subsystems
    - Subsystems – Incremental Development involving software items
    - Software Items* – Waterfall Development involving software units
- The requirements volatility problem stemming from requirements ambiguity can be mitigated via stronger requirements engineering processes such as prototyping

* Larger software Items could be also incremental where each increment is a waterfall
Some Whimsical Remarks on Requirements

- The Waterfall Model assumes that the requirements can be determined with high-fidelity before actual development starts
  - The mantra in real estate is “Location, location, location”
  - The key to successful software development is “Requirements, requirements, requirements”
- Unfortunately, requirements volatility is a fact of life
  - New, agile methodologies are designed to cope with the influx of new requirements
    - “…we have come to value responding to change over following a plan”*
  - However, I still suggest listening to Yogi Berra:
    - "If you don't know where you are going, you will wind up somewhere else"

* Source: [Agile 2001]
Conclusion - The Experts’ Voice

I believe in this [waterfall] concept, but the implementation ... is risky and invites failure”

~~~ Winston Royce, 1970

“[Iterative development] projects are not easier to set up, to plan, or to control just because they are iterative. The project manager will actually have a more challenging task, especially during his or her first iterative project, and most certainly during the early iterations of that project, when risks are high and early failure is possible.”

~~~ Philippe Kruchten, 2000

Concurrency, scaling, and scope management are equally difficult problems in all methodologies
To Get Back to the Mood after the Q/A...

It winds along the face of a cliff
This path which I long to explore,
And over it dashes a waterfall,
And the air is full of the roar
And the thunderous voice of waters which sweep
In a silver torrent over some steep.
It clears the path with a mighty bound
And tumbles below and away,
And the trees and the bushes which grow in the rocks
Are wet with its jeweled spray;

From "A Coloured Print by Shokei," by Amy Lowell
# Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>CDR</td>
<td>Critical Design Review</td>
</tr>
<tr>
<td>DBDD</td>
<td>Database Design Description</td>
</tr>
<tr>
<td>IDD</td>
<td>Interface Design Description</td>
</tr>
<tr>
<td>IRS</td>
<td>Interface Requirements Specification</td>
</tr>
<tr>
<td>PDR</td>
<td>Product Design Review</td>
</tr>
<tr>
<td>SCDR</td>
<td>Software Critical Design Review</td>
</tr>
<tr>
<td>SAD</td>
<td>Software Architecture Description</td>
</tr>
<tr>
<td>SDD</td>
<td>Software Design Description</td>
</tr>
<tr>
<td>SDP</td>
<td>Software Development Plan</td>
</tr>
<tr>
<td>SPDR</td>
<td>Software Preliminary Design Review</td>
</tr>
<tr>
<td>SRR</td>
<td>Software Requirements Review</td>
</tr>
<tr>
<td>SRS</td>
<td>Software Requirements Specification</td>
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<td>SWRR</td>
<td>Software Requirements Review</td>
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## References

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<tr>
<td>Agile 2001</td>
<td>Agile Alliance, Manifesto for Agile Software Development, 2001</td>
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<tr>
<td>Stachowiak 1973</td>
<td>Stachowiak, H., Allgemeine Modelltheorie (General Model Theory), Springer, Wien, New York, 1973</td>
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Poem passage on Slide 18 is courtesy of themargins.net: