Programming Languages and the Power Grid

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Programming Languages and the Power Grid: Outline

1. The Power Grid
   - Design of a national power grid
   - Why and how to balance the grid
   - Two things to keep in mind on national scale

2. Case Study
   - Entelios AG
   - The right language for the job
   - Technology roadmap
   - Experiences

3. Unfair Generalizations
   - Two notable pitfalls of OO designs in practice
   - The “2-out-of-3” rule of dealing with project risk

4. Programming Languages and the Power Grid
   - Chains of availability
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Caution! Font size will vary!
The Power Grid
“Design is not about the actual choices you make. It is about the alternatives you have considered.”
Designing a Power Grid: *Where do you want to be?*

- Reliability
- Costs
- Other:
  - Environment
  - Sustainability
  - Major Risks

You are here!
Balancing the *Power Grid*

Germany: 4 TSOs
Balancing the **Power Grid**

Industry Principle: Generation follows Consumption

Three level controller for reserve power (simplified):
- Frequency reserve (PRL), 20..200 mHz
- Secondary reserve (SRL), > 200 mHz, automatic
- Replacement reserve (MRL), > 15 min, manual

Germany: 15 GW per Hz

50.2 Hz
50.0 Hz
49.8 Hz

(put your favorite frequency here…)

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Balancing the *Power Grid*

Generation follows Consumption, except for Wind and Solar.

Germany: 11% Renewables. 20 GW Peak (of 80 GW total) on 18. August 2012.
Balancing the *Power Grid*

**Dynamic Balance**

Generation follows Consumption, except for Wind and Solar, and Demand-Response Management.

- Load management *within* large consumers common, e.g. Xstrata Zink GmbH
- Extremely complex body of national regulations
- Europe: Early VC-funded companies (Entelios AG)
The Power of the Power Grid: *Mind the Order of Magnitude!*

- **100 mW** personal, mobile phone
- **100 W** residential, refrigerator
- **100 kW** industrial, climate control
- **100 MW** industrial, arc furnace
- **100 GW** national, power grid (e.g. Germany)

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The Batteries of the Power Grid: *Sometimes Not What You Expect*

You say: derinding buffer of a paper mill (Stora Enso, Eilenburg, Saxony), …

… I say: battery with 200 MWh capacity.
Case Study
Founded in 2010 by Oliver Stahl, Stephan Lindner and Thomas (Tom) Schulz
VC-Funded (Series A completed in 2011 with a Dutch lead investor)
Based in Germany (Munich, Berlin), employee range 20-50 + network of partners
Runs its own Network Operations Center (NOC), with its own Balancing Area.
Prequalified for providing Operating Reserve to German TSOs.

Services

Production of electrical energy by intelligent management of industrial consumers.

Exploiting dormant load flexibility, in particular in-production buffers.

Software-as-a-Service for Demand Response “(Virtual) Batteries Included”.
1. Knowing the rules of the game:
   Law, body of other regulations and actual practice.

2. The actual business model:
   "We sell A to B, who buy it because of C."
   Exercise: Find A, B and C. (Note: Answers are graded in EUR +/-.)

3. Finding industrial participants:
   Why do they join? (Suppliers, found by sales process.)

4. Technology:
   Effective, reliable, usable, … and ever changing.
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Entelios AG in Context
The right language for the job... So what is the job?

Key Functionality
• Back-office system: 24/7, soft-realtime signal acquisition / control signals from / to industrial participants and grid operators. Sample rate: 2/min – 20/min
• Front-office system: Soft-realtime GUI for interactive planning and execution of curtailment events (load reduction) under time constraints. Task rate: 0 – 1/min
• Remote connection (M2M) to industrial participants via Internet, UMTS, GSM
• Fieldbus-Interface to the PLCs of the SCADA system of the industrial participants
• Interface to the operations centers of the grid operators (IEC-104, MOLS, …)
• Unsupervised Recovery from transient failure: UPS, auto restart at various levels

Additional Functionality (and there is a lot more...)
• Monitoring GUI, background screens
• Archiving of essentially all communications with external parties
• Export of time series data for periodic and ad-hoc analysis
• Periodic transfer of data to Energy Data Mgt. / Workflow / Trading Systems
• Various reports to participants and TSOs (for prequalification and quality control)
The right language for the job… *Ways to do a job*

Snippets of how we do things:

• Cross-platform development from Day 1: Win 2008 Srv, Win 7 {32,64}-bit, MacOS X, {Deb,Ubu,SuSE}-Linux, embedded Linux.

• For new hires: “You can BYO anything you know how to use, or you get a Windows Notebook from us. Your choice.” So far: 100% Windows Notebooks, two of them actually used to work in Windows.

• Productivity = Hours * Effectiveness. (The second factor is the important one.)

Some principles:

• A successful system allows the user to do what she wants.

• Each tool is suitable for some task, but for other tasks there might be better tools.

• Choose which tools *not* to use. (Features bundled with your favourite toolkit…)

• The hardest task of software engineering: getting rid of something.
Bits of Our Technology Roadmap (on the Rearview Mirror)

GUI
- Python, BaseHTTPServer
- C#, WinForms
- Erlang, Yaws, HTML5, CSS3, JS
- Ruby, Rails

Server
- Python, MySQL
- C#
- Erlang, MySQL

embedded
- 3rd party
- C/C++
- Python
- Erlang
Green Field: Initial Pragmatic Choices

Embedded System and Server-Side Core:

• 1st choice of embedded platform turned out to be unlucky. (Their 3rd level support couldn’t / wouldn’t fix their own product…) \(\rightarrow\) Supplier eventually dropped.

• 2nd choice was a lucky one. Devices optionally with an embedded Linux, incl. a Python 2.6 \(\rightarrow\) Embedded Python! (Performance rel. to C not an issue for us.)

• Natural choice: Use Python server-side, too! \(\rightarrow\) 99% overlap of embedded and server-side code, it’s just “--embedded” to disable database access etc.

• Considerable part written in functional style, but of course not replacing for by home grown “foreach” calling a lambda.

Client-side GUI:

• Initial boundary condition: “Must run in .NET on Windows.”

• Original concept required high amount of GUI interaction. \(\rightarrow\) Rich client

• Choice of GUI toolkit (2010): WinForms (mature, aged L&F) vs. WPF (modern L&F)

• \(\rightarrow\) F# with WPF, using Functional Reactive Programming for time series.
Requirements have Changed: *Adapting the Early Choices*

**Redesign Server-Side Core in 2012:**
- Increased scalability requirements along various dimensions: sample rate, redundancy, customers, industrial participants
- (Thread-)Concurrency in Python: It can be made to work, but that is tiring…
- Severely short on system tests. (Reasonable coverage in unit tests.)
- → **Erlang/OTP**: for concurrency and testability (and excellent previous experience)
- → Python stays for some functions (ad-hoc data analysis, forecasting, …)

**Redesign Client-side GUI:**
- Requirements have changed considerably:
  - Much less interaction required than original envisioned.
  - Also used for non-interactive monitoring.
- Only component to have repeatedly relapsed below roll-out Q-level:
  - Interaction performance (largely due to WPF’s approach to widgets)
  - Memory leaks (widget resources, async + lazy + side-effects)
- → **Web-GUI in Erlang**, less interactive signal plots. Phasing-out F# / WPF.
Redesigned Embedded Platform in 2013:
• Motivation: Multi-controller access and redundancy, faster data acquisition, automatic catching-up after network outage.
• → Erlang/OTP on the embedded platform
• → Porting effort for platform, submitting a few patches upstream.

Unifying Look-and-Feel of the GUI in 2013:
• Focus changed from functionality (=> each component brings its own UI style) to an integrated look-and-feel with brand recognition.
• Important for marketing the software as a “solution”.
• Closer integration with the business-side software (workflow, ERP, accounting etc.)
Random Bits of Experience…

…with Python:
• Has served us well, in particular on the embedded platform.
• No “unsolvable” issues, rich library, program straight-forward to extend.
• Relatively large step from prototype (script) to production code.
• Major thread-headache for realtime system, especially controlled shutdown and restart.

…with F# / WPF:
• Has worked for us, and we do use it in production. Good fit with original concept.
• The only part of the software the relapsed several times below roll-out quality level.
• In practice, we find it hard to modify or correct other people’s F# / WPF code.
• One F# issue reported back to Microsoft (initializer). (Turned out version 2.0.0.0 ≠ 2.0.0.0.)

…with Erlang/OTP:
• Everybody working on the project and beyond is happy with it. (Read this again, if you want.)
• Relatively slow project start: building, testing, establish common coding style, etc.
• Three issues reported back to Erlang/OTP team (ARM middle endian; dialyzer bug; _/utf8).
Random Bits of Experience...

...with MySQL:
• The only technology that was with us from the start, and still is today.
• Nearly exclusively used in “archive mode”.
• SQL: data must be rectangular. Lucky for us, our (time series) data is!
• Had to hack our own MySQL client in Erlang: not easy, one size does not fit all
• Insulated by about 30 min. worth of buffering from the soft real-time system.
• Amazing issues (v5.1): float in – another float out; character encoding broken.
• Nothing that we couldn’t work around.

...with HTML5 / CSS3 / JS:
• Surprise: Browser compatibility less of an issue than expected.
• We keep it even simpler: CSS is hard to test, JS is browser-side (for us)
• Wrote our own CSS parser (in Erlang) for detecting dead (unreachable) CSS code.
Observations on Erlang/OTP

- Relatively small step from prototype and production code.
- Easy to understand other people’s code. (The questions “How do I define a gen_server in monadic style?” and “When do they get around to object-oriented Erlang?” disappear quickly.)
- Often you refactor in Erlang and your code becomes 2x smaller, and that alone feels like you did something right. (Java: You refactor, it is clearly the right thing to do, and you constantly ask yourself is the result worth all the cruft.)
- Production code often stays stable for years. (This means modularization is effective.)
- Make well-tested building blocks can be recombined into different systems.
- Final production code much smaller (say 5x c.t. Java), once it is finished. Not necessarily faster to develop, though.
- Difficult: Shutting down processes properly without undue error propagation. (Eventually, I wrote a small combinatorial program to generate and study all possible ways a gen_server example can exit, and what happens then.)
- Common_test: Very useful, but noisy…
- Great: interactively debugging a live system.
- Great: resilience (Example: system was limping on for hours, did not loose any data)
- Great: hot code-update (we do the easy cases, only)
What We Have Added to Erlang/OTP

Our own build mechanism “ebt” (= Entelios/Erlang Build Tool), including:

- build the system (on Linux, Windows and MacOSX)
- build the embedded system (on ARM-based Linux, on server as cross-compile)
- run the tests (Common_test). Variant: run only the fastest tests until 5 min. are up
- run the tests with cover analysis (Cover)
- pragma to silence Dialyzer (static code analysis):  ... % dialyzer: -warn_failing_call
- internationalization (“i18n”): crawls the code for certain function calls, then runs GNU gettext
- check basic coding standards (no tabs etc.): crawl .erl, .hrl, .yaws, .css, .js, etc.
- compile Mercurial version into the code: every build knows its version!
- run Leex/Yecc (parser generators)

General libraries within our Erlang code base:

- strings (UTF-8 as binary), timestamps (ms precision), option lists (= uptight proplists)
- Tracing (application-defined, not by structure of process tree)
- Running Gnuplot, GLPK and Python (on Linux, Windows and MacOSX)
- Password file access
- validation of HTML5, CSS3
What We Are NOT Using from Erlang/OTP

Meta-programming and ways to obscure function calls at the call site:
- parse_transformations: consider using Erlang, repeat
- (define own) behaviour: we did and we rolled it back for reducing code redundancy
- \(-\)import: when fingers get sore, \(-\)define an abbreviation

“Let it crash!” and error discipline in general:
- In a test: yes
- In the webserver: no.
- In a library: probably not. (It might end up part of the webserver, and it usually does.)
- We like \{ok,Value\} | \{error,Reason::atom(),Details::proplist()\} a lot.
- There is a difference between a programming error (crash is good) and bad input.
- check_MyType(Arg) functions returning \(\text{ok}|\{\text{error},\_\_\_\}\) do an in-depth check of a data structure (incl. dynamic invariants); used as assertion \(\text{ok} = \text{check}(\ldots)\) or in a case.

Type annotations, documentation and helping with static type analysis:
- \(-\)compile(export_all): just \(-\)export
- \(-\)spec: nice feature, we avoid it. Found in places where proper documentation was due.
Unfair Generalizations
When OO in the wild fails (1)... “Jupiter Design”

class Point

class Rect

class EverythingElseAndTheGUI_too
When OO in the wild fails (1)… "Jupiter Design"

```c
class Point

class Rect

class EverythingElseAndTheGUI_too

method innocuous_looking(void) {
    indirectly_access(potentially, any, instance, variable);
}
```
When OO in the wild fails (1)…

“Jupiter Design”

Cause of Failure: Human Error…
(“overuse of global variables”)

```cpp
class Point

class Rect

class EverythingElseAndTheGUI_too

method innocuous_looking(void) {
    indirectly_access(potentially, any, instance, variable);
}
```
...but it’s also related to the tools! *The Economics of Redesign*
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“No redesign zone” – Can’t afford it.
...but it’s also related to the tools! The Economics of Redesign

“No redesign zone” – Can’t afford it.
...but it’s also related to the tools! *The Economics of Redesign*

![Diagram showing effort required for next redesign, with "No redesign zone" zone indicating can’t afford it. Lines represent different methods: OO-ish and FP-ish, with one line showing routing new arguments through functions.](image)
When OO in the wild fails (2)...

“State Limbo”

def handle_request(self):
    # self represents ‘moon’
    self.cloudy_moon_setter()
    # self represents ‘cloud’
    self.rise_and_shine()
    # self represents ‘sun’
    return ‘ok’
When OO in the wild fails (2)…

“State Limbo”

```
handle_call(Request, _, S1) ->
  % state S1 is ‘moon’
  S2 = cloudy_moon_set(S1)
  % made a new state S2 = ‘cloud’
  S3 = risen_and_shining(S2)
  % yet another state S3 = ‘sun’
  {reply, ok, S3}. % set next state
```
When OO in the wild fails (2)… “State Limbo”

def handle_request(self):
    # self represents ‘moon’
    self.cloudy_moon_setter()

    # What is the state now?
    # Clean up OR press on?
    # But how?

    return ‘bummer’
When OO in the wild fails (2)… “State Limbo”

 handle_call(Request, _, S1) ->
% state S1 is ‘moon’

S2 = cloudy_moon_set(S1)
% The state is S1 + side-effects
% from cloudy_moon_set/1.
% Server state S1 is still around,
% can be used to clean up.

{reply, bummer, S1}. 
## The “2-out-of-3” Rule of Dealing of Project Risk

<table>
<thead>
<tr>
<th>Functionality</th>
<th>Duration (Completion Date)</th>
<th>Cost (Burn Rate)</th>
<th>Fixed</th>
<th>Risk</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>FD</td>
<td>More resources</td>
<td>Traditional “waterfall” project</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>FC</td>
<td>Sliding deadlines</td>
<td>Traditional “institutional” project</td>
<td></td>
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<tr>
<td>DC</td>
<td>Feature starvation</td>
<td>“Agile” project</td>
<td></td>
<td></td>
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<tr>
<td>F</td>
<td>Slow &amp; expensive</td>
<td>Confused “agile” with <em>carte blanche</em></td>
<td></td>
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</tr>
<tr>
<td>D</td>
<td>Unusable result</td>
<td>Endless financial renegotiation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Unusable result</td>
<td>Endless feature reprioritizing</td>
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</tr>
<tr>
<td>FDC</td>
<td>Project locks up</td>
<td>“Ignore the risks” project, will blow up</td>
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</tr>
<tr>
<td>-/-</td>
<td>Loss of focus</td>
<td>“Nothing gets ever done” project</td>
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</tbody>
</table>

### Examples

**FD:** Module of deep space probe (dependability requirements, launch window)

**FC:** Next version of major operating system (functionality previews, limited resources for fixing bugs)

**DC:** Milestone of start-up company (expectations of partners, hours/day limited)
Programming Languages and the Power Grid
Summary

- “Power Grid” sounds more fixed and set than it actually is.
- Society’s preferences for the power grid can and do change.
- Entelios AG is a young company helping stabilize the grid using the approach of Demand Response.
- *Functional Programming* concepts and tools have served us well in accomplishing this.
- Systems connected to the power grid could benefit by re-evaluating the basic assumptions.
Time for Questions