Development of a Model and a Mobile Computing Framework for Effective Self-Management of Type II Diabetes

Jay Urbain, PhD
urbain@msoe.edu

Electrical Engineering and Computer Science Department
Milwaukee School of Engineering,
Clinical Translational Science Institute of Southeast Wisconsin,
Medical College of Wisconsin
Project Partners

- Clinical Translational Science Institute of Southeast Wisconsin
  - Create a borderless, synergistic biomedical research enterprise that will accelerate the translation of research discoveries into new and improved medical treatments.

- Project partners:
  - Jay Urbain, Edith Burns, Paul Kndusen, Megan Fedders, Bambi Wessel, Ann Swartz, Scott Strath
  - Milwaukee School of Engineering, Medical College of Wisconsin, University of Wisconsin-Milwaukee
  - Clinical Translational Science Institute of Southeast Wisconsin
  - *urbain@msoe.edu, {eaburns,pknudson,mfedders, wessel}@mcw.edu, {sstrath, aswartz}@uwm.edu*
Diagnosed and undiagnosed diabetes among people aged 20 years or older, United States, 2010
CDC Diabetes Fact Sheet

• Age 20 years or older: 25.6 million, or 11.3% of all people in this age group, have diabetes.
• Age 65 years or older: 10.9 million, or 26.9% of all people in this age group, have diabetes.
• Health care costs 2.3x
• Growing rapidly.
Estimated number of new cases of diagnosed diabetes among people aged 20 years or older, by age group, United States, 2010

Estimated diabetes costs in the United States, 2007 CDC Diabetes Fact Sheet

- Total (direct and indirect): $174 billion
- Direct medical costs: $116 billion
- Indirect costs: $58 billion
  - (disability, work loss, premature mortality)
Introduction

• Optimum control of (Type II Diabetes) T2DM requires active self-management:
  – Diet
  – Exercise
  – Complex medication dosing

• Can demonstrate significant improvement in patient outcomes.
Chaotic Disease

• Many factors may influence glucose measures:
  – Makes interpretation of glucose levels difficult
  – Lack of consistency between glucose and behavior
  – “catastrophizing” high values

• Feedback on success in management is highly dependent on infrequent glycated hemoglobin (HbA1c) measures
  – Measured by health care provider – out of patients’ control
  – Removed in time and place from health behavior choices
Goal of project

- *Help patients become experts in managing health habits*
- Use self-monitored blood glucose (SMBG) as a tool to enhance self-management
  - Allows rapid measurement of blood glucose
  - Provide assistance in appropriate interpretation of results
  - Advise and assist in complex, real-time behavior choices
    - Diet, physical activity, medication
Real-time Mobile Feedback

• Migrate *clinical logic* to smart phone:
  – Mobile
  – Real-time
  – Individualized to user
  – Multi-modal: Voice, audio, text, and visual data options
  – Automated data transmission & feedback
  – Increased sophistication and power of clinical feedback through Web interface
  – Provide clinician access to patterns of glucose levels, health habits, etc.
Clinical Logic
Project Stages

• Software Architecture
  – Drs. Edit Burns and Paul Knudsen worked with Software Architecture students as SME’s to define requirements, design software architecture.

• Submitted CTSI Proposal

• Received small pilot grant March 2010.

• System design and prototyping
  – Iterative Process

• Clinical Pilot
  – Show efficacy
Software Architecture

- Work Context
- Use Cases
- Architectural Drivers
- Quality Scenarios
- Sequence Diagrams
- Architectural Views
  - Design patterns, layers, persistence, components.
iSmart Work Context

Patient
- Login to the system
- Check blood sugar
- Track medication
- Track diet
- Track activity
- Manage care plan
- Coordinate other medical tasks

Analyst
- Analyst profile
- Reporting configuration
- Query results
- Login to the system
- Configure report
- OLAP query request

iSMART System
- Clinician profile and patient list
- Patient data
- Patient care plan
- Login to the system
- Analyze patient data
- Manage care plan

Glucometer
- SMBG readings

Clinician
- Login to the system
- Manage care plan

System Administrator
Use Cases

- Track Vital Signs
- Track Meds
- Track Symptoms
- Track Diet
- Track Physical Activity
Architectural Drivers/Qualities

• Security
• Usability
• Modifiability
• Reliability
• Availability
Quality Scenarios

• Develop quality scenarios for each architectural driver. Example:

### Usability

<table>
<thead>
<tr>
<th>Source</th>
<th>Request</th>
<th>Environment</th>
<th>Artifact</th>
<th>Response</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient</td>
<td>Wants to enter something in the system</td>
<td>Patient Access Interface/Mobile Device is available for use, although may not have a connection to rest of system.</td>
<td>Patient Access Interface/Mobile Device</td>
<td>Entry is validated and accepted by the system</td>
<td>Entire process takes patient &lt; 30 seconds. (Glucose reading not included in this time.)</td>
</tr>
</tbody>
</table>
Sequence Diagrams

UC1: Track Blood Glucose
Architectural Views – Component/Layers

Client
- Analyst Interface
- Clinician Interface
- Patient Interface
  - Smart Phone
  - Web

HTTP Requests ➔ HTTP Reply

Presentation
- Tomcat Web Container
  - Model
  - Controller
  - View

Domain
- Domain Services
- Data Access Object

Data
- SQL Queries ➔ Data
- Database Server
  - MySQL
  - Ismart Database
Presentation – Front Controller Design Pattern
Technology, Design

• Smart Phone:
  – Android/Java

• Server:
  – Amazon Web Services – Elastic Cloud Compute (EC2) instance with Elastic Block Storage (ELB).
  – Ubuntu, MySQL database, Tomcat Web Server, Java/Servlets/JSP.
Design Features

• Distributed application –
  – App can work on/off network.
  – Local phone database automatically synchronizes with server database
    • Vector clock (logical clock)
    • Eventual consistency database model
  – Clinicians can review individual or aggregated patient data, set parameters via Web-interface.
  – Inherently scalable cloud-based computing solution.
  – Design not limited to diabetes.
Data warehousing style
Star Schema

Dimensional Index

Measurement: vital (SMBG, HR, etc.), med, diet, activity, symptom
Rev 1 - Initial Proto

What did you measure?
blood glucose (mg/dL)

What was your measurement?
65

65.0 < 70.
Hypoglycemia treatment: Treat hypoglycemia with 15 grams of carbohydrates every 15 minutes until glucose is over 90.
Initial Prototype Evaluation

- Timestamp correlation difficult
  - Use logical clocks
- Patients overwhelmed with choices
  - Focus on SMBG, insulin, diet & activity
- Symptoms not correlated with entry
  - Integrate symptom with other entries
- Trend detection algorithm
  - SMBG unstable
- Multi-model feedback
  - Tabular, graphical
- Compliance
  - Alerts
- Non-technical population
  - Teach patients how to use smart phone
- Further simplify entry
  - Smart type-ahead
- Automatic monitoring of activity level
  - Pedometer
Rev 2 – Flow

Android
Notifications

iSmart reminder!
Log glucose, insulin, diet, & activity

April 19, 2012
5:56 PM

Clear

Thu, Apr 19, 2012
06:15
List

Vital:

blood glucose (mg/dL)

Value:

Note:

Clear
Save

Thu, Mar 29
06:00
Trend
List

When:
before breakfast

107
ok
Goal average 90-130
10-sample mean: 131
3-sample mean: 123
10-sample stddev: 46

Stable Trend:
Once we have dietary and activity information, then we can give feedback on what worked and what could be tweaked.

OK

Android
Graph

Insulin
Diet
Activity

Glucose

Edge

Graph

$\text{Rev 2 – Flow}$
### Blood Glucose Trend

**Goal average**: 90-130
10-sample mean: 131
3-sample mean: 123
10-sample stdev: 46

**Stable Trend:**
Once we have dietary and activity information, then we can give feedback on what worked and what could be tweaked.

<table>
<thead>
<tr>
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<th>N</th>
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<th>Min</th>
<th>Avg.</th>
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<td>112</td>
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<td>2012-04-01</td>
<td>3</td>
<td>97</td>
<td>110</td>
<td>115</td>
</tr>
</tbody>
</table>

**Blood glucose > 250. Hyperglycemia treatment: Your glucose is elevated**

Thu, Apr 5, 2012

![Graph showing blood glucose levels over time](image)
## Usage Log

**User: urbain**

### Aggregate Patient Usage

<table>
<thead>
<tr>
<th>Patient Id</th>
<th>Vital</th>
<th>Med</th>
<th>Diet</th>
<th>Physical</th>
<th>Symptom</th>
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<tr>
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<tr>
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<td>1003</td>
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<td>1</td>
<td>0</td>
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</table>

Questions: urbain@msoe.edu
## Reports

*User: urbain*

### Select Patient ID: 1555215554

<table>
<thead>
<tr>
<th>Timestamp</th>
<th>Type</th>
<th>Measurement</th>
<th>Quantity</th>
<th>Units</th>
<th>Note</th>
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<tbody>
<tr>
<td>2012-04-14 11:20:25.0</td>
<td>diet</td>
<td>muffin</td>
<td>400</td>
<td>calories</td>
<td></td>
</tr>
<tr>
<td>2012-04-12 17:33:08.0</td>
<td>med</td>
<td>insulin</td>
<td>5500</td>
<td>units</td>
<td>Long-acting</td>
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<tr>
<td>2012-04-14 17:52:20.0</td>
<td>vital</td>
<td>blood glucose</td>
<td>200</td>
<td>mg/dL</td>
<td></td>
</tr>
<tr>
<td>2012-03-14 17:25:40.0</td>
<td>vital</td>
<td>blood glucose</td>
<td>200</td>
<td>mg/dL</td>
<td></td>
</tr>
<tr>
<td>2012-03-14 17:25:40.0</td>
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<td>blood glucose</td>
<td>200</td>
<td>mg/dL</td>
<td></td>
</tr>
</tbody>
</table>
### Limits

**User: urbein**

<table>
<thead>
<tr>
<th>Patient ID:</th>
<th>default</th>
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<tbody>
<tr>
<td>Time:</td>
<td>episode</td>
</tr>
<tr>
<td>Type:</td>
<td>vital</td>
</tr>
<tr>
<td>Measurement:</td>
<td>blood glucose</td>
</tr>
</tbody>
</table>

**Limit Quantity**

<table>
<thead>
<tr>
<th>Low:</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td>High:</td>
<td>250</td>
</tr>
</tbody>
</table>

**Messages**

<table>
<thead>
<tr>
<th>Low:</th>
<th>Hypoglycemia treatment: Treat hypoglycemia with 15 grams of carbohydrates every 15 minutes until glucose is over 90.</th>
</tr>
</thead>
<tbody>
<tr>
<td>High:</td>
<td>Hyperglycemia treatment: Your glucose is elevated. Call your health care team if you feel ill. Be sure to take your medication, eat wisely, and drink plenty fluids.</td>
</tr>
<tr>
<td>OK:</td>
<td>At goal. Keep up the good work. All your effort is keeping you right where you need to be.</td>
</tr>
</tbody>
</table>

**Limits for Patient ID: 0**

<table>
<thead>
<tr>
<th>Type</th>
<th>Measurement</th>
<th>Quantity Low</th>
<th>Quantity High</th>
<th>Message Low</th>
<th>Message High</th>
<th>Message OK</th>
</tr>
</thead>
<tbody>
<tr>
<td>vital</td>
<td>blood glucose</td>
<td>70</td>
<td>250</td>
<td>Hypoglycemia treatment: Treat hypoglycemia with 15 grams of carbohydrates every 15 minutes until glucose is over 90.</td>
<td>Hyperglycemia treatment: Your glucose is elevated. Call your health care team if you feel ill. Be sure to take your medication, eat wisely, and drink plenty fluids.</td>
<td>At goal. Keep up the good work. All your effort is keeping you right where you need to be.</td>
</tr>
<tr>
<td>vital</td>
<td>heart rate</td>
<td>40</td>
<td>150</td>
<td>Heart rate too high.</td>
<td>Heart rate too high.</td>
<td>Heart rate within range.</td>
</tr>
<tr>
<td>diet</td>
<td>calories</td>
<td>1500</td>
<td>1500</td>
<td>Hit the scales</td>
<td>Time for more</td>
<td>Great job</td>
</tr>
</tbody>
</table>
Preliminary Findings

• Adoption dependent on patient population
• Impossible to make UI too simple or convenient
• Multi modal – speech popular
• Prompts & feedback improve compliance
• Knowing that data is being reviewed regularly appears to improve compliance
Future Directions

• Adaptive disease modeling
• Integrate real-time activity
  – Added pedometer, want more: GPS, etc.
• Integrate other vitals
  – Interested in beat-to-beat HR
• MCW/CTSI service
• Social aspects
• Incentives, QuadMed