CS 520
Theory and Practice of Software Engineering
Spring 2022

Process-model-based guidance for medical clinicians

April 12, 2022
Many medical procedures are complex and inherently error prone

- Multiple specialty teams
- Concurrent activities
- Team communication
- Exceptional situations where problems are identified and need to be addressed
Goal: Support Human Performance in the Operating Room

Reduce preventable errors by providing guidance to surgical teams carrying out medical procedures (or processes)

• Model normative situations and non-normative (i.e. unusual or exceptional) situations where problems are identified and must be addressed

• Provide automated guidance based on a validated medical process model both offline and online
Limitations of Previous Approaches

- Process guides (e.g., checklists) often do not model some situations that are highly complex and high risk — e.g., non-normative situations, team communication

- Most guides are static so lack dynamic process context

- Dynamic guides hardcode the process so cannot be easily updated when that process changes

Contact: hconboy@cs.umass.edu
Our approach

1. **Model** the recommended medical procedure (or process)
2. **Validate** this process model
3. **Provide automated guidance** to the medical clinicians based on the process model
Our approach

1. **Model** the recommended medical procedure (or process)
2. **Validate** this process model
3. **Provide automated guidance** to the medical clinicians based on the process model

After the real-world process changes, modify the process model, revalidate that model, and automatically update the guidance.
Case studies

• Blood transfusion
• Chemotherapy
• Emergency room care
• Infusion therapy
• Memory and aging care
• Cardiac surgery
Case studies

• Blood transfusion
• Chemotherapy
• Emergency room care
• Infusion therapy
• Memory and aging care
• Cardiac surgery
  – Aortic valve replacement (AVR)
  – Coronary artery bypass grafting (CABG)
Collaborators

- Medical clinicians
  - e.g., Anesthesiologists, Doctors, Nurses
- Human factors and UI experts
  - e.g., Brigham & Women’s Hospital STRATUS lab
- Biomedical engineers
  - e.g., Mass General Hospital OpenICE lab
- Computer scientists
1. Model the medical process

1.1) Elicit the medical process
   • From published documents and medical clinicians

1.2) Define the medical process model
   • Use the Little-JIL process modeling language which is expressive and has rigorous execution semantics
Elicit the medical process
Little-JIL Process Modeling Language

- Hierarchically decomposes the process model into steps

- Has rigorous execution semantics

[Cass2000]
Little-JIL Process Modeling Language

- Hierarchically decomposes the process model into steps

- Has rigorous execution semantics

[13]

[Cass2000]
Little-JIL Process Modeling Language

• Hierarchically decomposes the process model into steps

• Has rigorous execution semantics

[ Cass2000 ]
Little-JIL Process Modeling Language

- Hierarchically decomposes the process model into steps
- Has rigorous execution semantics

[Cass2000]
Heparinization Modeled in Little-JIL

1. **Perform heparinization**
   - HDR Recommended Heparin Dose $> 400$
   - Report suspicion of heparin resistance
   - Administer HDR recommended heparin then verify ACT
   - Turn on pump sucker
   - Follow heparin resistance protocol
   - Gather anesthesiology, perfusion, and surgery team leaders
   - Treat heparin resistance
   - Report low ACT

2. **Decision to use pump sucker**
   - YES
     - Try to address problem LowACT
     - Address problem NoMoreAlternatives

3. **Carried out by:** Perfusion
   - Anesthesiology and Perfusion
   - May report problem LowACT
   - May report problem NoMoreAlternatives
   - Surgeon

4. **HDR Recommended Heparin Dose**
   - $> 400$

5. **Decision to use pump sucker**
   - YES
     - Try different alternatives to address problem LowACT
     - May report problem NoMoreAlternatives
Heparinization Modeled in Little-JIL

- Perform heparinization
- Gather anesthesiology, perfusion, and surgery team leaders
- Report suspicion of heparin resistance
- Administer HDR recommended heparin then verify ACT
- Turn on pump sucker
- Follow heparin resistance protocol
- Treat heparin resistance
- Report low ACT

Carried out by: Perfusion

HDR Recommended Heparin Dose > 400

- Carried out by: Anesthesiology and Perfusion
- May report problem LowACT

Decision to Use Pump Sucker == YES

- Carried out by: Perfusion

- Address problem NoMoreAlternatives

- Carried out by: Surgeon

- Carried out by: Anesthesiology, Perfusion, Surgeon
- Try different alternatives to address problem LowACT
- May report problem NoMoreAlternatives
Heparinization Modeled in Little-JIL

- Perform heparinization
  - Carried out by: Perfusion

  - Gather anesthesiology, perfusion, and surgery team leaders
  - Administer HDR recommended heparin and verify ACT
  - Turn on pump sucker
  - Follow heparin resistance protocol

  - Report suspicion of heparin resistance
  - HDR Recommended Heparin Dose > 400

- Decision to use pump sucker == YES
  - Carried out by: Perfusion
  - Turn on pump sucker
  - Follow heparin resistance protocol

  - Address problem NoMoreAlternatives
  - Try different alternatives to address problem LowACT

- Treat heparin resistance
  - Carried out by: Anesthesiology, Perfusion, Surgeon
  - May report problem NoMoreAlternatives

- Report low ACT
  - Carried out by: Surgeon

- Try to address problem LowACT
  - Carried out by: Perfusion
  - Anesthesiology and Perfusion
  - May report problem LowACT

- Address problem NoMoreAlternatives
  - Carried out by: Perfusion
  - Anesthesiology, Perfusion, Surgeon
  - May report problem NoMoreAlternatives
Heparinization Modeled in Little-JIL

- HDR Recommended Heparin Dose > 400
- Decision To Use Pump Sucker == YES

1. perform heparinization
2. report suspicion of heparin resistance
3. gather anesthesiology, perfusion, and surgery team leaders
4. administer HDR recommended heparin then verify ACT
5. turn on pump sucker
6. follow heparin resistance protocol
7. treat heparin resistance
8. report low ACT

Carried out by:
- Perfusion
- Carried out by: Anesthesiology and Perfusion
- May report problem LowACT
- Carried out by: Anesthesiology, Perfusion, Surgeon
- Try different alternatives to address problem LowACT
- May report problem NoMoreAlternatives

Address problem NoMoreAlternatives

Report LowACT

Carried out by: Surgeon
Heparinization Modeled in Little-JIL

1. **Perform Heparinization**
   - HDR Recommended Heparin Dose > 400
   - Report suspicion of heparin resistance
   - Carried out by: Perfusion

2. **Administer HDR Recommended Heparin**
   - Then verify ACT
   - Carried out by: Perfusion

3. **Turn on Pump Sucker**
   - Decision to Use Pump Sucker == YES
   - Carried out by: Perfusion

4. **Follow Heparin Resistance Protocol**
   - Carried out by: Anesthesiology and Perfusion

5. **Gather Anesthesiology, Perfusion, and Surgery Team Leaders**
   - Carried out by: Perfusion

6. **Treat Heparin Resistance**
   - Address problem NoMoreAlternatives
   - Report low ACT
   - Carried out by: Surgeon

7. **Try to Address Problem LowACT**
   - May report problem LowACT

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**HDR Recommended Heparin Dose**

- **> 400**

**Decision To Use Pump Sucker**

- **== YES**
2. Validate the medical process model

- Manual reviews by medical clinicians
- Automated analyses (e.g., model checking)
Automatically generated process review document

Table Of Contents

- perform heparinization
  - report suspicion of heparin resistance
  - administer HDR recommended heparin dose
  - verify ACT
    - administer heparin dose
    - verify target ACT achieved
    - determine post-heparin AC
  - determine ACT
    - obtain blood sample test
    - test blood sample for heparin resistance
    - confirm target ACT achieved
  - follow heparin resistance protocol
    - gather anesthesiology, perfusion, surgery team leaders
  - treat heparin resistance
    - administer additional heparin dose
    - verify ACT
    - determine additional heparin dose
    - administer heparin dose
    - verify target ACT achieved
    - treat heparin resistance
      - treat heparin resistance
      - treat heparin resistance

Perform Heparinization

Requires:

The following team members should be scheduled and available: anesthesiologist, perfusionist, surgeon. Additionally, the following people and equipment should be scheduled and available: CPB pump, patient.

The following should be provided: target ACT (in s), HDR recommended heparin dose (in u/kg), decision to use pump sucker.

What to do:

To perform this step, the following should be done in the listed order:

- If HDR recommended heparin dose (in u/kg) is greater than 400 u/kg, report suspicion of heparin resistance
- administer HDR recommended heparin then verify ACT

  - If the problem Low ACT is identified, follow heparin resistance protocol should be done. If follow heparin resistance protocol is completed without problems, this step should continue on to the next step. If the problem Low ACT is identified, then this step should be considered completed with a problem and the identified problem should be reported.

  - If decision to use pump sucker is YES, turn on pump sucker

Outcomes:

If the problem Low ACT is identified, then this step should be considered completed with a problem and the identified problem should be reported.

Report Suspicion Of Heparin Resistance

Requires:

The perfusionist is needed to perform this step.

The HDR recommended heparin dose (in u/kg) should be provided.

What to do:
Automatically generated process review document

Table Of Contents

- perform heparinization
  - report suspicion of heparin resistance
  - administer HDR recommended heparin dose
  - verify ACT
- administer heparin dose
- verify target ACT achieved
- determine post-heparin ACT
  - determine ACT
    - obtain blood sample test
    - test blood sample for
  - confirm target ACT achieved
- follow heparin resistance protocol
  - gather anesthesiology, perfusionist, surgery team leaders
- treat heparin resistance
  - administer additional heparin
  - verify ACT
  - determine additional heparin dose
  - administer heparin dose
  - verify target ACT achieved
  - treat heparin and/or AT III
  - determine if patient was heparin pre-operatively
- treat heparin deficiency

Perform Heparinization

Requires:

- The following team members should be scheduled and available: anesthesiologist, perfusionist, surgeon.
- Additionally, the following people and equipment should be scheduled and available: CPB pump, patient.

- The following should be provided: target ACT (in s), HDR recommended heparin dose (in u/kg), decision to use pump sucker

What to do:

- To perform this step, the following should be done in the listed order:
  - If HDR recommended heparin dose (in u/kg) is greater than 400 u/kg, report suspicion of heparin resistance
  - administer HDR recommended heparin then verify ACT
  - If the problem Low ACT is identified, follow heparin resistance protocol should be done. If follow heparin resistance protocol is completed without problems, this step should continue on to the next step. If the problem Low ACT is identified, then this step should be considered completed with a problem and the identified problem should be reported.
  - If decision to use pump sucker is YES, turn on pump sucker

Outcomes:

- If the problem Low ACT is identified, then this step should be considered completed with a problem and the identified problem should be reported.

Report Suspicion Of Heparin Resistance

Requires:

- The perfusionist is needed to perform this step.

- The HDR recommended heparin dose (in u/kg) should be provided.

What to do:
Automated analyses

• **Model checking:** Assumes that the modeled steps are performed correctly, but determines whether key steps are always done in the required sequence

• **Fault tree analysis:** What steps would need to be misperformed for a particular hazard to become likely to occur?

• **Discrete-event simulation:** Assess how different what if scenarios impact the potential outcomes
Little-JIL
integrated development environment
Little-JIL
integrated development environment
3. Provide process-model-based guidance to medical clinicians

- **Narration View** for supporting walking through selected training situations (i.e. offline)

- **“Smart” Checklist User Interface** dynamically providing context-aware support during real-world situations (i.e. online)
3. Provide process-model-based guidance to medical clinicians

- **Narration View** for supporting walking through selected training situations (i.e. offline)

- **“Smart” Checklist User Interface** dynamically providing context-aware support during real-world situations (i.e. online)

Similar to regression testing

After the real-world process changes, modify the process model, revalidate that model, and automatically update the guidance
3. Provide process-model-based guidance to medical clinicians

- **Narration View** for supporting walking through selected training situations (i.e. offline)

- **“Smart” Checklist User Interface** dynamically providing context-aware support during real-world situations (i.e. online)

*After the real-world process changes, modify the process model, revalidate that model, and automatically update the guidance*
Offline guidance for training

- Automatically generate a **narration view** providing a hypertext description to selectively explore the alternative paths through a given **process model**

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**Table Of Contents**

- perform heparinization
  - inform all teams about suspicion of heparin resistance
  - administer one or more heparin doses
    - administer HDR recommended heparin
    - announce heparin dose
    - verbally confirm heparin dose
    - give heparin dose as an intravenous
    - announce heparin dose given
  - verify target ACT achieved
    - determine cost-heparin ACT
    - determine ACT
      - obtain blood sample
      - test blood sample for heparin
      - announce ACT
      - confirm target ACT achieved
  - administer additional 5,000 to 10,000 units of heparin
    - verify ACT
  - determine additional 5,000 to 10,000 units of heparin
    - administer heparin
    - verify target ACT achieved
    - consider administering additional heparin maximum than verify ACT

**Perform Heparinization**

**Requires:**

- The following process performers should be scheduled and available: anesthesiologist, auto, nurse, perfusionist, surgeon. Additionally, the following resources should be scheduled and available: CPB pump, anticoagulation management system, patient.

- The following may be needed to perform part of this step: anesthesiologist, auto, nurse, perfusionist, surgeon. Additionally, the following may be needed during this step: CPB pump, anticoagulation management system, patient.

- The following should be provided: determination that patient was on heparin preoperatively, decision to use pump sucker, HDR recommended heparin dose, initial heparin dose, baseline ACT.

- The target ACT should be provided to this step and may be modified during the step.

**What to do:**

To perform this step, the following should be done in the listed order:

- If HDR recommended heparin dose is greater than 400, inform all teams about suspicion of heparin resistance

- administer one or more heparin doses
  - If the problem Low ACT is identified, follow suspected heparin resistance protocol should be done. If follow suspected heparin resistance protocol is completed without problems, this step should continue on to the next step. If the problem Low ACT is identified, then this step should be considered completed with a problem and the identified problem should be reported.

- If decision to use pump sucker is YES, turn on pump sucker

**Outcomes:**

- If the problem Low ACT is identified, then this step should be considered completed with a problem and the identified problem should be reported.
Online guidance: Smart Checklist User Interface

• Automatically create a “smart” checklist user interface to help each specialty team understand:
  – its own dynamic process context
  – the contexts of the other teams

• Dynamically update the user interface by matching the process model against monitored process execution events
  – Store the process history to create post-procedure documentation
Online guidance:
Smart Checklist User Interface (cont.)
Online guidance:
Smart Checklist User Interface (cont.)
Online guidance: Smart Checklist User Interface (cont.)

Similar to a debugger
Online guidance:
Post-procedure documentation

- Automatically create a **process history view** summarizing the actual path through the **process model** completed and can edit to further customize it
Process-model-based guidance framework

1. Reduce CPB pump flow by \( \frac{1}{2} \) if needed.
2. Assess LV wall motion if needed.
3. Make a decision about assessing LV wall motion.
4. Assess LV wall motion.
5. Review TEE findings to assess LV wall motion.
6. Reduce CPB pump flow to \( \frac{1}{2} \) L/min.
7. Address LV wall motion abnormalities.
8. Confirm bypass graft patency.
9. Treat LV wall motion abnormalities.
10. Provide inotropic/vasoactive support.
11. Insert aortic balloon pump.
12. Perform TEE to assess LV wall motion.

Decision: To assess LV wall motion = YES
Process-model-based guidance framework

Wean from bypass
- Reduce CPB pump flow by 1/2
- Assess LV wall motion if needed
- Make decision about assessing LV wall motion
- Assess LV wall motion
- Review TEE findings to assess LV wall motion
- Reduce CPB pump flow to 1 L/min
- Address LV wall motion abnormalities
- Confirm bypass graft patency
- Treat LV wall motion abnormalities
- Provide inotropic/vasoactive support
- Insert aortic balloon pump

Decision to Assess LV Wall Motion == YES
Usability

• UI expert design review
• Focus groups held to collect:
  – Questions, comments, and suggestions
  – System Usability Survey

<table>
<thead>
<tr>
<th>The System Usability Scale Standard Version</th>
<th>Strongly disagree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 I think that I would like to use this system.</td>
<td>⭕️ ⭕️ ⭕️ ⭕️ ⭕️</td>
<td></td>
</tr>
<tr>
<td>2 I found the system unnecessarily complex.</td>
<td>⭕️ ⭕️ ⭕️ ⭕️ ⭕️</td>
<td></td>
</tr>
<tr>
<td>3 I thought the system was easy to use.</td>
<td>⭕️ ⭕️ ⭕️ ⭕️ ⭕️</td>
<td></td>
</tr>
<tr>
<td>4 I think that I would need the support of a technical person to be able to use this system.</td>
<td>⭕️ ⭕️ ⭕️ ⭕️ ⭕️</td>
<td></td>
</tr>
<tr>
<td>5 I found the various functions in the system were well integrated.</td>
<td>⭕️ ⭕️ ⭕️ ⭕️ ⭕️</td>
<td></td>
</tr>
<tr>
<td>6 I thought there was too much inconsistency in this system.</td>
<td>⭕️ ⭕️ ⭕️ ⭕️ ⭕️</td>
<td></td>
</tr>
<tr>
<td>7 I would imagine that most people would learn to use this system very quickly.</td>
<td>⭕️ ⭕️ ⭕️ ⭕️ ⭕️</td>
<td></td>
</tr>
<tr>
<td>8 I found the system very cumbersome to use.</td>
<td>⭕️ ⭕️ ⭕️ ⭕️ ⭕️</td>
<td></td>
</tr>
<tr>
<td>9 I felt very confident using the system.</td>
<td>⭕️ ⭕️ ⭕️ ⭕️ ⭕️</td>
<td></td>
</tr>
<tr>
<td>10 I needed to learn a lot of things before I could get going with this system.</td>
<td>⭕️ ⭕️ ⭕️ ⭕️ ⭕️</td>
<td></td>
</tr>
</tbody>
</table>
Results

• Automatically provide online and offline guidance to medical teams to reduce preventable errors

• Leverage a process model capturing best practices

• During focus group evaluations, clinicians could see many benefits of such guidance
Some future directions

- Continuing to develop the process-model-driven guidance system based on clinician feedback

- Further evaluating this system by conducting clinical human simulation studies
  - Collaborating with STRATUS Simulation Laboratory at Brigham and Women’s Hospital
APPLICATION OF SOFTWARE ENGINEERING TOOLS AND TECHNIQUES
## Smart Checklist repo

<table>
<thead>
<tr>
<th>Directory</th>
<th>Description</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>bin</td>
<td>Add description code</td>
<td>5 years ago</td>
</tr>
<tr>
<td>client</td>
<td>Bug fix to ensure that the latest comments are a...</td>
<td>13 days ago</td>
</tr>
<tr>
<td>jWebSocket-1.0</td>
<td>Support for leaf tasks to change colors</td>
<td>3 years ago</td>
</tr>
<tr>
<td>juliette_server_release</td>
<td>Updated to the latest Interpreter release</td>
<td>3 months ago</td>
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<td>juls-and-scripts</td>
<td>Bug fix for the BloodTypeKind in the Heparin Re...</td>
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<tr>
<td>jwebsocket</td>
<td>Bug fix each checklist item should be associate...</td>
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</tr>
<tr>
<td>.classpath</td>
<td>Change classpath and add JWebSocket jar files</td>
<td>5 years ago</td>
</tr>
<tr>
<td>.gitignore</td>
<td>Two agents working code</td>
<td>5 years ago</td>
</tr>
<tr>
<td>.project</td>
<td>Initial Commit</td>
<td>5 years ago</td>
</tr>
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<td>README.md</td>
<td>Requires Java 1.8 on the PATH and JAVA_HOME</td>
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<td>makeServer.sh</td>
<td>Switched from relative (class)paths to fully-qual...</td>
<td>3 years ago</td>
</tr>
<tr>
<td>runJuliette-timestamp...</td>
<td>Improved multiple team support by allowing the ...</td>
<td>3 years ago</td>
</tr>
<tr>
<td>setupEnv</td>
<td>Updating the setupEnv to have the classpath in...</td>
<td>7 months ago</td>
</tr>
<tr>
<td>startClient.sh</td>
<td>Change agent selection web page to be the index</td>
<td>5 years ago</td>
</tr>
<tr>
<td>startServer.sh</td>
<td>Switched from relative (class)paths to fully-qual...</td>
<td>3 years ago</td>
</tr>
</tbody>
</table>

### Releases

- No releases published
- Create a new release

### Packages

- No packages published
- Publish your first package

### Contributors

- karaggeorge George Karagi...
- christov S C
- hconboy Heather Conboy

### Languages

- JavaScript 54.4%
- Java 22.2%
- Shell 11.1%
- HTML 8.5%
- Batchfile 2.5%
- CSS 1.3%
Smart Checklist framework architecture

1. User command (encoded)
2. User command (decoded)
3. View updates (decoded)
4. View updates (encoded)

Little-JIL process model [JUL file]
Smart Checklist framework architecture

Little-JIL process model [JUL file]

1. User command (encoded)

2. User command (decoded)

3. View updates (decoded)

4. View updates (encoded)

Little-JIL interpreter

Smart Checklist Server

Smart Checklist Client (i.e. UI)

Similar to Java virtual machine
Little-JIL process model [JUL file]

1. User command (encoded)

2. User command (decoded)

3. View updates (decoded)

4. View updates (encoded)

Mediator design pattern
Mediator design pattern

The **Mediator** is responsible for all of the communications among a set of **Colleagues**. (The Colleagues never communicate directly with each other.)

Example:
- Smart Checklist server is the Mediator and Colleagues are Little-JIL interpreter and Smart Checklist UI.

https://en.wikipedia.org/wiki/Mediator_pattern
Process history trace
Process history trace

Similar to Java stack trace
Testability
Process Driven Guidance for Complex Surgical Procedures

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Abstract

Surgical team processes are known to be complex and error prone. This paper describes an approach that uses a detailed, validated model of a medical process to provide the clinicians who carry out that complex process with offline and online guidance to help reduce errors. Offline guidance is in the form of a hypertext document describing