Contents

- Introduction
- Motivation
- Silo Introduction
- Knowledge Evolution
- Case Study: Thyroid Cancer
**Introduction:** Number of Deaths by Cause

- **Cardiovascular** – 17.65 million
- **Cancer (Thyroid + Head & Neck Cancer)** – 8.93 million
- **Diabetes** – 3.19 million
- **Kidney** – 1.19 million

---

**Annual number of deaths by cause, World, 2016**

Data refers to the specific cause of death, which is distinguished from risk factors for death, such as air pollution, diet and other lifestyle factors. See sources for further details on definitions of specific cause categories.

Source: Institute for Health Metrics and Evaluation (IHME); Global Terrorism Database (GTD); Amnesty International

https://ourworldindata.org/causes-of-death
Background

Thyroid Cancer Incidence Rate:
- The incidence of thyroid cancer has increased steadily and consistently in many developed countries, most notably in South Korea, where the incidence increased by more than sevenfold, from 6.3 per 100,000 population in 1999 to 47.5 per 100,000 population in 2009.

Thyroid Cancer Mortality Rate:
- The mortality rate has remained stable for several decades.
The incidence rate is the number of new cases per population at risk in a given time period.

The observed incidence rate in year 2012 was obtained from the Korea Central Cancer Registry.

Introduction: Early Diagnosis and Treatment

Step 1: Awareness and Accessing Care
- Awareness of symptoms, seeking and accessing care

Step 2: Clinical Evaluation, Diagnosis and Staging
- Accurate Clinical Diagnosis
- Diagnostic testing and staging
- Referral for treatment

Step 3: Access to Treatment
- Accessible, high quality, and accurate Treatment

Number of Death
Incidence Rate
Introduction: IT Convergence with Medical Services

1. Patient Registration
2. Patient Check-up
3. Laboratory Tests
4. Diagnosis
5. Treatment Prescription
6. Pharmacy (Taking Medicine)
7. Tele monitoring

Right Patient?
Right Diagnosis Decision?
Right Prescribed Treatment?
Right medication, at right time, and right dose?
Right level of glucose, hypertension, and cholesterol?

Intelligent Clinical Decision Support System (On Network)

✓ Telecommunication
✓ Computing
✓ Artificial Intelligence
✓ Audio-visual Systems
✓ Enterprise Softwares
✓ Healthcare Technology

remendations, Alerts, Reminders

Hypertension, Physical Activity, Medication
Motivation

Need to develop AI + medical convergence type "intelligent medical support service platform"

✓ Need to develop intelligent medical platform technology to enhance patient care.
✓ ICT + medical personnel experience required

[CDSS Global Market Size Forecast]

Market Size ($ in Millions)

<table>
<thead>
<tr>
<th>Year</th>
<th>2018</th>
<th>2019</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>$558</td>
<td>$613.6</td>
<td>$725.4</td>
<td></td>
</tr>
</tbody>
</table>

Rule of Knowledge base in CDSS

Decision Support System

User Interface → Inference Engine → Knowledge Base → Knowledge Authoring → Experts’ Heuristics → Big Data → Open Knowledge

- Lab Technicians
- Business Analyst
- Physical Instructor
- Nutritionist
- Physicians

Big Data

- Healthcare data
- Pharmaceutical
- Laboratory and X-rays
- Activity Tracking
- Business Analysis
- Care-giver and Tele monitoring
- Notification & Reminders
- Educational
- Social media
- Mobile apps
- Social networks
- Government & Corporations
- Computers
- Smartphones

Open Knowledge

- Health
- Nutrition
- Physical activity

User Interface

- User

Knowledge Base

- Experts’ Heuristics
- Big Data
- Open Knowledge

Knowledge Authoring

- User Interface
- Inference Engine
- Knowledge Base
Knowledge Representation – From Tacit To Executable
Silo Construction Process

1. Mind Map
2. Decision Tree
3. Authoring Tool
4. Knowledge Base
5. Recommendation

Enterprise Architect
Knowledge Engineer
Physician
Production Rules
Patient Data

Knowledge Base
Recommendation

TEIN CC Cooperation Center
Asi@Connect
Formal Representation of Tacit Knowledge

1-1 Objectives for CDSS Intervention

1-2 Guidelines selection

2 Clinical Knowledge Model creation

2-1 Knowledge Modeling: (Mind Map)

2-2 Knowledge Modeling: (Decision Tree)

Team Involved
- Surgeons
- Knowledge Engineers

Objectives for CDSS Intervention
- Patient Evaluation for Surgery
- Recommendation of appropriate Surgery Procedure

1. Guidelines selection
   - NCCN Guidelines
   - ATA Guidelines
## Iterative Decision Tree VS Decision Tree

<table>
<thead>
<tr>
<th>Key Features</th>
<th>Iterative Decision Tree</th>
<th>Decision Tree</th>
<th>Key benefits of IDT over DT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rich and flexible formalism</td>
<td>Rich and flexible Example: Complex logical expression at nodes</td>
<td>Rich but strict Example: Only single concept evaluation at nodes</td>
<td>IDT give freedom to domain experts • To model clinical knowledge in a more flexible way.</td>
</tr>
<tr>
<td></td>
<td>Example: Enable multi-valued domain concept evaluation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Easily understandable to stakeholders</td>
<td>Compact Example: The rich and flexible formalism enables compact model</td>
<td>Non compact Example: Strict formalism cause huge DT model</td>
<td>IDT allows the capture of: • Detailed guidelines semantics in a more compact manner.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support Manageable model</td>
<td>Re-using knowledge patterns Example: Knowledge patterns are re-used with cyclic structure</td>
<td>No support for patterns Example: The top-down non-cyclic approach result in huge model</td>
<td>IDT handles the patterns in CPG with: • Repeating cycles</td>
</tr>
<tr>
<td></td>
<td>• Expressive power at nodes enable shorten branch</td>
<td>• It includes duplicate knowledge in branches</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data dependence</td>
<td>No Example: Source of knowledge • CPGs • Domain expert experiences • Domain expert heuristics</td>
<td>Yes Example: Machine Learning model needs: • Data</td>
<td>IDT allows to reflect • Sheer amount of online knowledge • CPGs • Other evidence-based models</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mind Maps to Decision tree (Example)

- Concepts
- Concepts Priority
- Relationships
## Mind Maps to Decision tree (Formalism)

<table>
<thead>
<tr>
<th>IDT Artifact</th>
<th>Description</th>
<th>Remarks (Decision Node: DN, Leaf Node: LN, Decision Branch: DB)</th>
</tr>
</thead>
</table>
| **Condition Node** (Rectangle) | **Semantic**: Decision Node | Examples:  
i. DN1: TSH (Normal, Elevated, Subnormal)  
a. DB1: Normal  
b. DB2: Elevated OR Subnormal  
ii. DN2: Pregnancy (Y,N) AND Sex (M,F)  
a. DB1: Y AND F  
b. DB2: N AND F  
**Formal BNF:**  
\[
\text{conditionNode} ::= \{\text{domainTerm}\} | \{\text{domainTermBinary}\}  
\text{domainTermBinary} ::=  
\{\text{domainTerm}\}(\text{com. Opr})(\text{domainValue})[[\log. Opr](\text{domainValue})]|  
\{\text{domainTerm}\}(\text{com. Opr})(\text{domainTerm})|  
\{\text{domainTerm}\}(\text{log. Opr})(\text{domainTerm})|
\]  
| **Activity Node** (Rectangle with curved corners) | **Semantic**: Activity Node / Leaf Node | Examples:  
i. DN1: FNA (Yes, No)  
a. DB1: Yes  
b. DB2: No  
ii. LN1: EA or RFA  
**Formal BNF:**  
\[
\text{activityNode} ::= \{\text{conditionNode}\} | \{\text{leafNode}\}  
\text{leafNode} ::= \{\text{any recommendation}\} | \{\text{domainTerm}\}
\]  

### Condition Node:
- This node use to evaluate some condition
- Represented in yellow rectangle

### Activity Node:
- This node use to perform some medical activity or process
- Represented in brown rounded corners rectangle
**Composite Condition Node:**
- This node is used to evaluate single or multiple attributes.
- Represented in a green diamond symbol.

**Recommendation Node:**
- This node represents the final recommendation.
- Represented in a blue rectangle.

**Formal BNF:**

- **Condition Node**:
  
- **Decision Branch**
  - Single/multiple attributes

- **Color (Optional):**
  - Yellow

- **When to use:**
  - Attribute value set is limited
  - Alternate for Composite Condition Node

- **Examples:**
  - DN1: TSH {Normal, Elevated, Subnormal}
    - DB1: Normal
    - DB2: Elevated OR Subnormal
  - DN2: Pregnancy {Y,N} AND Sex {M,F}
    - DB1: Y AND F
    - DB2: N AND F

**Note:**
Value set of TSH and other concepts are known as domain values.

**Formal BNF (Decision Branch):**

- **Decision Branch**
  - Binary Branch
  - Composite Branch

**Activity Node**
- Semantic: Decision Node / Leaf Node
- Decision branch Making: single/multiple attributes
- Color (Optional): Brown
- When to use:
  - Attribute represents outcome of some complex medical process
  - Attribute represents recommendation for some complex medical process

- **Examples:**
  - DN1: FNA {Yes, No}
    - DB1: Yes
    - DB2: No
  - LN1: EA or RFA

**Formal BNF:**

- **Activity Node**
  - Semantic: Decision Node / Leaf Node
  - Decision branch Making: single/multiple attributes
  - Color (Optional): Light Blue

- **When to use:**
  - This node represents the final recommendation.

- **Examples:**
  - LN1: Surgery: L
  - LN2: Surgery: (DL) OR Surgery (I)
Rule Extraction (Example)

- Decision Path

**IF** Symptom and Sign = Yes and Clinical History = Yes and Physical Exam = Yes and ECG = Abnormal and NTproBNP >= 125 and LVEF < 40

**Then**

Disease = HFrEF Confirmed
Guideline based strategy

1. Patient initial observation for tumor presence
2. Ordering sonography
3. Evaluate sonography results and evaluate patients
4. Based on severity and size of the tumor decision is made for further Surgery evaluation using FNA
Thyroid Cancer Follow Up Recommendation

Expert Tree (Mind Maps) -> Formal Iterative Decision Tree - IDT (CKM-Clinical Knowledge Model)

- Separate Actions & Conditions
- Draw relationships

- Composite condition
- Draw relationships

- Extract conditions and recommendation
- Concrete relationships

Redundant Information X
Thyroid Cancer Follow Up Recommendation

Formal IDT (CKM-Clinical Knowledge Model) -> Rules (Production Rules) [ Using decision tables ]

Traversing:
• Top-Down

Traversing:
• Left-Right
Thyroid Cancer Surgery Recommendation

Formal IDT (CKM-Clinical Knowledge Model) -> Rules (Production Rules) [ Using Decision Table ]

European Union
Thyroid Cancer Surgery Recommendation

Formal IDT (CKM-Clinical Knowledge Model) -> Rules (Production Rules) [ Using the Algorithm]

Algorithm 1: Transform IDT into Rules
- Procedure IDTToRules
  - Input: IDT as XML-Model
  - Output: rules as Set
    1. idt.model, idt_flattenedModel as IDT, Object Model;
    2. idt.model = parseIDT(idt);
    3. idt_flattenedModel = flattenIDT(idt.model);
    4. rules = GenerateRules(r as Rule, rules, idt_flattenedModel);
  - return rules;

Algorithm 2: Rules Generation
- Procedure GenerateRules
  - Input: r as Rule, rules as Set, idt_flattenedModel as IDT, Object Model
  - Output: ruleSet as Set
    1. currentRule = idt_flattenedModel.currentRule;
    2. if currentRule != LeafNode OR currentRule = ActivityNode then
      1. r.conditionExpression = currentRule.Value;
      3. ruleSet.addRule = r;
      4. return ruleSet;
    5. end
    6. foreach e : Edge in currentRule do
      7. r.condition = e.conditionExpression;
      8. idt_flattenedModel.currentRule = e.TargetNode;
      9. return ruleSet = GenerateRules(r, ruleSet, idt_flattenedModel);
    10. end

(a) Algorithm 1: Transform IDT into Rules
(b) Algorithm 2: Rules Generation

[Diagram of Thyroid Cancer Surgery Recommendation]

[Diagram of Algorithm 1 and Algorithm 2]
Knowledge Execution : Dashboard

- **Existing Patients**
  - Dashboard shows existing patients to edit or delete.

- **New Patient**
  - It also provides facility to add new patient record using Add New Patient button.

### Add New Patient

### Edit Existing Patient

### Delete Existing Patient

---

**Patient List**

<table>
<thead>
<tr>
<th>Patient ID</th>
<th>Name</th>
<th>Recent Recommendation</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pats.0292</td>
<td>John Roe</td>
<td>Fine needle aspirations (FNA)</td>
<td><img src="edit.svg" alt="Edit" /> <img src="delete.svg" alt="Delete" /></td>
</tr>
<tr>
<td>Pats.0291</td>
<td>John Roe</td>
<td>Fine needle aspirations (FNA)</td>
<td><img src="edit.svg" alt="Edit" /> <img src="delete.svg" alt="Delete" /></td>
</tr>
<tr>
<td>Pats.0290</td>
<td>John Roe</td>
<td>Fine needle aspirations (FNA)</td>
<td><img src="edit.svg" alt="Edit" /> <img src="delete.svg" alt="Delete" /></td>
</tr>
<tr>
<td>Pats.0289</td>
<td>John Roe</td>
<td>Fine needle aspirations (FNA)</td>
<td><img src="edit.svg" alt="Edit" /> <img src="delete.svg" alt="Delete" /></td>
</tr>
<tr>
<td>Pats.0288</td>
<td>John Roe</td>
<td>Fine needle aspirations (FNA)</td>
<td><img src="edit.svg" alt="Edit" /> <img src="delete.svg" alt="Delete" /></td>
</tr>
<tr>
<td>Pats.0287</td>
<td>John Roe</td>
<td>Fine needle aspirations (FNA)</td>
<td><img src="edit.svg" alt="Edit" /> <img src="delete.svg" alt="Delete" /></td>
</tr>
<tr>
<td>Pats.0286</td>
<td>John Roe</td>
<td>Fine needle aspirations (FNA)</td>
<td><img src="edit.svg" alt="Edit" /> <img src="delete.svg" alt="Delete" /></td>
</tr>
<tr>
<td>Pats.0285</td>
<td>John Roe</td>
<td>Fine needle aspirations (FNA)</td>
<td><img src="edit.svg" alt="Edit" /> <img src="delete.svg" alt="Delete" /></td>
</tr>
<tr>
<td>Pats.0284</td>
<td>John Roe</td>
<td>Fine needle aspirations (FNA)</td>
<td><img src="edit.svg" alt="Edit" /> <img src="delete.svg" alt="Delete" /></td>
</tr>
<tr>
<td>Pats.0283</td>
<td>John Roe</td>
<td>Fine needle aspirations (FNA)</td>
<td><img src="edit.svg" alt="Edit" /> <img src="delete.svg" alt="Delete" /></td>
</tr>
</tbody>
</table>
### Follow Up Recommendation Intervention

<table>
<thead>
<tr>
<th>Patient UHN</th>
<th>Patient Name</th>
<th>Sex</th>
<th>Age</th>
<th>Encounter Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paris.0289</td>
<td>John Roe</td>
<td>Female</td>
<td>51</td>
<td>1/1/2017</td>
</tr>
</tbody>
</table>

#### Thyroid Nodule Evaluation
- Size of Nodule: 0
- Suspicion Patterns on Image
- Extrathyroidal Extension (ETE): No
- Suspicious LN metastasis (Immunohistochemistry): No

**Recommendation:** Fine needle aspirations (FNA)

#### FNA and CNB Information

<table>
<thead>
<tr>
<th>FNA</th>
<th>CNB</th>
</tr>
</thead>
<tbody>
<tr>
<td>History of Radiation: No</td>
<td></td>
</tr>
<tr>
<td>Family History of Thyroid cancer: No</td>
<td></td>
</tr>
<tr>
<td>Pregnancy: No</td>
<td></td>
</tr>
<tr>
<td>Delivery Done: No</td>
<td></td>
</tr>
<tr>
<td>Gestation Period</td>
<td></td>
</tr>
<tr>
<td>Multilocularity of Thyroid nodule: No</td>
<td></td>
</tr>
<tr>
<td>Increase in size of Thyroid nodule: No</td>
<td></td>
</tr>
<tr>
<td>Central lymph nodes: No</td>
<td></td>
</tr>
<tr>
<td>Lymph Node Metastasis: No</td>
<td></td>
</tr>
<tr>
<td>Level Metastasis: No</td>
<td></td>
</tr>
<tr>
<td>Distant Metastasis: No</td>
<td></td>
</tr>
<tr>
<td>Compressive Symptoms: No</td>
<td></td>
</tr>
<tr>
<td>Voice Change: No</td>
<td></td>
</tr>
<tr>
<td>Based upon clinical concern: No</td>
<td></td>
</tr>
</tbody>
</table>
Active tab FNA (FNA Information)
Active tab CNB
(CNB Information)
CDSS Intervention: Shows the recommendation of a patient based on patient profile and symptoms

The decision comes from knowledge base
Results: Surgical patients

System Accuracy: 81.5%
Overall KB rules: 3034

Interpretation:
• Total Patients: 292
• Patient Distribution: 20 paths
### Results: Surgery – TT (Total Thyroidectomy)

<table>
<thead>
<tr>
<th>Surgery (TT)</th>
<th>CBN</th>
<th>EA or RFA</th>
<th>No Recom</th>
<th>Surgery (L)</th>
<th>Isthmectomy</th>
<th>SNU Total</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-TT</td>
<td>154</td>
<td>2</td>
<td>2</td>
<td>16</td>
<td>0</td>
<td>154</td>
<td>86.36</td>
</tr>
<tr>
<td>S-L</td>
<td>31</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>106</td>
<td>136</td>
<td>76.47</td>
</tr>
<tr>
<td>Isthmectomy</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>50.00</td>
</tr>
<tr>
<td><strong>CDSS Total</strong></td>
<td>165</td>
<td>2</td>
<td>8</td>
<td>1</td>
<td>120</td>
<td>292</td>
<td>81.51</td>
</tr>
</tbody>
</table>

#### Accuracy

- **Surgery (TT):**
  - Accuracy: 86.36%

- **Surgery (L):**
  - Accuracy: 76.47%

- **Isthmectomy:**
  - Accuracy: 50.00%

#### Diagram:

Thyroid Cancer Treatment (Surgery) Recommendation Intervention

*Abbreviations:*
- AUS: Age of underdetermined significance
- CBN: Central lymph node
- CN: Central neck dissection
- CIN: Central lymph node dissection
- CT: Central lymph node dissection
- CT: Compressive lymph node
- D: Diagnostic lymph node surgery
- D: Diagnostic lymph node surgery excluding the central lymph node
- E: Extranodal extension
- F: Functional lymph node surgery
- F: Functional lymph node surgery excluding the central lymph node
- G: Gross tumor size
- G: Gross tumor size excluding the central lymph node
- H: Histological tumor size
- H: Histological tumor size excluding the central lymph node
- H: Histological tumor size excluding the central lymph node
- I: Invasive lymph node surgery
- I: Invasive lymph node surgery excluding the central lymph node
- L: Lymph node dissection
- L: Lymph node dissection excluding the central lymph node
- M: Metastatic lymph node surgery
- M: Metastatic lymph node surgery excluding the central lymph node
- N: Neoplastic lymph node surgery
- N: Neoplastic lymph node surgery excluding the central lymph node
- O: Operative lymph node surgery
- O: Operative lymph node surgery excluding the central lymph node
- P: Pathological tumor size
- P: Pathological tumor size excluding the central lymph node
- Q: Quanorantine lymph node surgery
- Q: Quanorantine lymph node surgery excluding the central lymph node
- R: Radioactive lymph node surgery
- R: Radioactive lymph node surgery excluding the central lymph node
- S: Stage
- S: Stage excluding the central lymph node
- T: Tumor size
- T: Tumor size excluding the central lymph node
- U: Uptake
- U: Uptake excluding the central lymph node
- V: Volume
- V: Volume excluding the central lymph node
- W: Width
- W: Width excluding the central lymph node
- X: Depth
- X: Depth excluding the central lymph node
- Y: Height
- Y: Height excluding the central lymph node
- Z: Zenital size
- Z: Zenital size excluding the central lymph node
Results: Surgery – L (Lobectomy)
Results: Surgery – I (Isthmectomy)
Manuscript ID amiajnl-2018-006960 entitled "Use of mind maps and iterative decision trees to develop a guideline-based clinical decision support system (CDSS) for routine surgical practice: Case study in thyroid nodules" which you submitted to the Journal of the American Medical Informatics Association, has been Published.

HyungWon Yu, JY Choi, Ho Sung Han, Seoul Natl Univ, Seongnam, Korea, Republic of Korea; Maqbool Husain, Taqdir Ali, Sungyoung Lee, Kyung Hee Univ, Suweon, Republic of Korea

Next Silo: Adrenal Tumor (Treatment)
Thanks

Email Address: taqdir.ali@oslab.khu.ac.kr