Human Health and Performance System
What is the goal?

• HRP – provide a systematic countermeasure to the known risks of exploration spaceflight.
• Start with gaining scientific understanding of the challenges.
• End with solutions and countermeasures that are delivered in the form of a vehicle subsystem and mission architecture focused on optimizing human health and performance.
Start with the Medical Risk?

Why? Because it becomes an integrating risk for Human Health and Performance.
ExMC Responsibilities

**Risk Title:** Risk of Adverse Health Outcomes & Decrements in Performance due to Inflight Medical Conditions

**Description:** Given that medical conditions will occur during human spaceflight missions, there is a possibility of adverse health outcomes and decrements in performance during these missions and for long term health.

**Other ExMC Risks:**
1. Risk of bone fracture due to spaceflight induced changes in bone.
2. Risk of ineffective or toxic medications due to long term storage.
<table>
<thead>
<tr>
<th>Risk or Concern</th>
<th>Current ExMC Ownership</th>
<th>Likely Future ExMC Ownership</th>
<th>Color</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concern of Clinically Relevant Unpredicted Effects of Medication</td>
<td></td>
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<td>Currently Own</td>
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<tr>
<td>Concern of Intervertebral Disc Damage upon and immediately after re-</td>
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<td></td>
<td>Health and Treatment Consequence</td>
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<tr>
<td>exposure to Gravity</td>
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<td></td>
<td>Long Term Health</td>
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<tr>
<td>Risk Factor of Inadequate Nutrition</td>
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<td>Performance Decrement with possible Medical Treatment</td>
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<td>Risk of Acute and Late Central Nervous System Effects from Radiation Exposure</td>
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<td>Risk of Acute Radiation Syndromes Due to Solar Particle Events (SPEs)</td>
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<tr>
<td>Risk of Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders</td>
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<td>Risk of Adverse Health &amp; Performance Effects of Celestial Dust Exposure</td>
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<tr>
<td>Risk of Adverse Health Effects Due to Host-Microorganism Interactions</td>
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<td>Risk of Adverse Health Event due to Altered Immune Response</td>
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<tr>
<td>Risk of an Incompatible Vehicle/Habitat Design</td>
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<tr>
<td>Risk of Bone Fracture due to Spaceflight-induced Changes to Bone</td>
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<tr>
<td>Risk of Cardiac Rhythm Problems</td>
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<tr>
<td>Risk Of Cardiovascular Disease and Other Degenerative Tissue Effects</td>
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<tr>
<td>From Radiation Exposure</td>
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<tr>
<td>Risk of Decompression Sickness</td>
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<td>Risk Of Early Onset Osteoporosis Due To Spaceflight</td>
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<tr>
<td>Risk of Impaired Control of Spacecraft/Associated Systems and Decreased Mobility Due to Vestibular/Sensorimotor Alterations, Associated with Spaceflight</td>
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<tr>
<td>Risk of Impaired Performance Due to Reduced Muscle Mass, Strength, and Endurance</td>
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<tr>
<td>Risk of Inadequate Critical Task Design</td>
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<tr>
<td>Risk of Inadequate Design of Human and Automation/Robotic Integration</td>
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<td>Risk of Inadequate Human-Computer Interaction</td>
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<tr>
<td>Risk of Ineffective or Toxic Medications Due to Long Term Storage</td>
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<tr>
<td>Risk of Injury and Compromised Performance Due to EVA Operations</td>
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<tr>
<td>Risk of Injury from Dynamic Loads</td>
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<tr>
<td>Risk of Orthostatic Intolerance During Re-Exposure to Gravity</td>
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<tr>
<td>Risk of Performance and Behavioral Health Decrement Due to Inadequate</td>
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<tr>
<td>Cooperation, Coordination, Communication, and Psychosocial Adaptation within a Team</td>
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<tr>
<td>Risk of Performance Decrement and Crew Illness Due to an Inadequate Food System</td>
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<tr>
<td>Risk of Performance Decrement and Adverse Health Outcomes Resulting from Sleep Loss, Circadian Desynchronization, and Work Overload</td>
<td></td>
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<tr>
<td>Risk of Performance Errors Due to Training Deficiencies</td>
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<tr>
<td>Risk of Radiation Carcinogenesis</td>
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<td>Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity</td>
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<tr>
<td>Risk of Renal Stone Formation</td>
<td>X</td>
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<tr>
<td>Risk of Spaceflight-Induced Intracranial Hypertension/Vision Alterations</td>
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</tr>
<tr>
<td>Risk of Unacceptable Health and Mission Outcomes Due to Limitations of In-flight Medical Capabilities</td>
<td>X</td>
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</tbody>
</table>

All of these risks interface with medical
Forward Plan

• Risk Mitigation Strategy
  – Planning
    • Concept of Operations Development (Ops Risk Reduction)
  – Characterization of Risk
    • Models and Metrics – Integrated Medical Model (IMM), MONSTR prototype
    • Active Data Gathering – Medical Consumables Tracker (MCT), biosensors, Flexible Ultrasound
  – Active Risk Reduction
    • Medical Support – Exploration Medical System Demonstrator (EMSD), Data Architecture
    • Technology Development – Oxygen Concentrator Module, Medical Suction, IVGen...
    • Training
    • Medical Decision Support
    • Integration of Medical with Vehicle Designers and ECLSS SMTs
The Medical System Goal

Provide the crew with the best chance to accomplish mission and get home healthy

Medical Operations
- Nominal Operations
- Contingency Operations
  - Routine
  - Urgent
  - Emergent
Background

• Exploration Medicine is unique:
  – NO regular resupply of materials
  – NO real-time communications
  – NO potential for evacuation if serious medical concerns arise.

• Medical care includes:
  – Screening
  – Prevention
  – diagnostic capability
  – treatment capability
  – follow up care
  – prognosis

• Characterize the likely medical risks
• Identify medical needs to address those risks
• Create a medical system to optimize crew response to those risks
• Engage in a testing pathway to validate and improve that system
• Work with vehicle engineers and flight surgeons to ensure useful implementation of that system

Exploration requires Stay and Fight Medicine, not Retreat Medicine.
Medical System Capture Diagram

- **Sensors**
  - Biomonitors
  - Environmental
  - EVA
  - Exercise
  - Behavioral

- **Tracking**
  - Consumables
  - Food
  - Medications
  - Fluids
  - Medical Eq.

- **Data Streaming**
  - Displays / Conferencing

- **Medical Equipment**
  - Imaging
  - 3-D Printing
  - Devices
  - Medications
  - Rehab

- **Performance**
  - Behavioral Monitor
  - Exercise Monitor

- **Training**
  - Medical Procedures
  - Imaging Techniques
  - Behavioral Intervention

- **EMS**
  - Caregiver Interface
  - Vehicle Data Interface

- **Intelligence Augmentation**
- **Models**
  - IMM
  - MONSTeR
  - Digital Astronaut
  - Radiation

- **References**
  - Pharmacologic
  - Toxicologic
  - Medical Imaging
  - Training Modules
  - Up-To-Date™

- **Medical Decision Support**
  - Telemedicine
  - Autonomy
  - Semi-autonomy

- **EMR**
  - AMP
Gap Restructuring

• Goal: develop a system
• Gap restructuring to enable that system
• Earliest Gap Needs:
  – Risk Assessment (Med08)
  – Concept of operations needs to guide system development (Med01)
  – Data Architecture development (Med07)
  – Early incremental testing of the system concepts (Med 01)
  – Vehicle Integration strategy (Med 01)
# Medical Risk

## New Gaps

<table>
<thead>
<tr>
<th>Med01</th>
<th>We do not have a concept of operations for medical care during exploration missions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Med02</td>
<td>We do not have the capability to provide a safe and effective pharmacy for exploration missions.</td>
</tr>
<tr>
<td>Med03</td>
<td>We do not know how we are going to apply personalized medicine to reduce health risk for a selected crew.</td>
</tr>
<tr>
<td>Med04</td>
<td>We do not have a defined rehabilitation capability for injured or de-conditioned crew members during exploration missions.</td>
</tr>
<tr>
<td>Med05</td>
<td>We do not know how to train crew for medical decision making or to perform diagnostic and therapeutic medical procedures to enable extended mission or autonomous operations.</td>
</tr>
<tr>
<td>Med06</td>
<td>We do not know how to define medical planning or operational needs for ethical issues that may arise during exploration missions.</td>
</tr>
<tr>
<td>Med07</td>
<td>We do not have the capability to comprehensively process medically-relevant information to support medical operations during exploration missions.</td>
</tr>
<tr>
<td>Med08</td>
<td>We do not have quantified knowledge bases and modeling to estimate medical risk incurred on exploration missions.</td>
</tr>
<tr>
<td>Med09</td>
<td>We do not have the capability to predict estimated medical risk posture during exploration missions based on current crew health and resources.</td>
</tr>
<tr>
<td>Med10</td>
<td>We do not have the capability to provide computed medical decision support during exploration missions.</td>
</tr>
<tr>
<td>Med11</td>
<td>We do not have the capability to minimize medical system resource utilization during exploration missions.</td>
</tr>
<tr>
<td>Med12</td>
<td>We do not have the capability to mitigate select medical conditions</td>
</tr>
<tr>
<td>Med13</td>
<td>We do not have the capability to implement medical resources that enhance operational innovation for medical needs</td>
</tr>
</tbody>
</table>
The Concept of Operations Drives System Design
Gap Restructuring Enables System Creation

- Safe and Effective Pharmacy
- Oxygen Delivery
- Medical Suction
- Ultrasound Imaging
- Laboratory Analysis
- Biosensors/EKG

Risk

1. Concept of operations
2. Pharmacy recommendation
3. Select technologies
4. Integrated medical system
5. Optimized medical system

Capability
How to decompose the work

Incremental and Iterative Approach

Pedigree: DoDAR

Relationships between research divisions in the Exploration Medical Capability Element.
The HHP Goal

HHP System Operations
- Risk monitoring
  - Vehicle
  - Environment
  - Crew
  - SYSTEM
- Countermeasure readiness and deployment
- Maximize mission objective attainment while minimizing crew casualty

Comm Delay
No Evac
No Resupply

Depart → Transit 1 → Planetary

Transit 2

HHP System?
Medical Data Architecture

Ground Based and Vehicle Data Architectures:
- Clinical Operational Needs
- Research Data Capture
- Long Term Health Information

• Flight Surgeon/BME
• External Consults

Mirrored Delayed Data Presentation for situational awareness/support

Vehicle Exploration Medical System
- Crew Medical Officer
- Crew Medical Support

Real-Time Data Processing for Crew
ExMC Data Architecture (ARC)

**Data Sources Layer**
- Structured
  - Health Records
  - Medical Records
  - Clinical Trials
  - Other
- Unstructured
  - Medical devices
  - Monitoring System
  - Images
  - Logs & Notes
  - Exercise Machine
  - Other
- Streams
  - Bio Sensors
  - Env. Sensors
  - Other

**Data Storage Layer**
- Data Assets
  - Knowledge Models
    - EHR
    - Documents
    - Sensor
    - Vitals
  - Other
- Integrated Data Platform
- Data Service
  - Annotate
  - Correlate
  - Classify
- Data Models

**Analytical Layer**
- Clinical Decision Support System
- Analytics Data Mart
- Knowledge Base

**Discovery & Analytics**
- Reports
  - Dashboard
- Data Mining
  - Text Classification
  - Computational Statistics
- Modeling & Analytics
  - Diagnostic
  - Predictive
- Discovery
  - Ontological Search
- Real Time Apps
  - Alerts
- Cognitive Computing
  - Adaptive, Interactive, Contextual

**User Interface**
- Applications & Prototypes
- User Interface & Visualization

**Metadata & Data Standards**
- Federated Access & Delivery Infrastructure (FADI)

**Data Virtualization**
# Ground-based Data Architecture (JSC)

## Identifying Data Sources

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMR</td>
<td>Extract, Transform &amp; Load Data</td>
</tr>
<tr>
<td>LSAH</td>
<td>Cleanse Data</td>
</tr>
<tr>
<td>SMOT</td>
<td>Data Profile &amp; Verification</td>
</tr>
<tr>
<td>PMC</td>
<td>Exception Handling</td>
</tr>
<tr>
<td>LSDA</td>
<td>Workflow &amp; Rules Management</td>
</tr>
<tr>
<td>Other</td>
<td>Batch Processing</td>
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<tr>
<td></td>
<td>Realtime Stream Processing</td>
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</table>

## Acquiring Data Sources

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
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<tbody>
<tr>
<td>EMR</td>
<td>Processed Data sources</td>
</tr>
<tr>
<td>LSAH</td>
<td>Operational &amp; Transactional Data</td>
</tr>
<tr>
<td>SMOT</td>
<td>Historical &amp; Trend Data</td>
</tr>
<tr>
<td>PMC</td>
<td>Reference &amp; Meta Data</td>
</tr>
<tr>
<td>LSDA</td>
<td>Audit &amp; Exception Data</td>
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</tbody>
</table>

## Organizing Data Sources

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processed Data sources</td>
<td>Store datasets as source data</td>
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</table>

## Analyzing Data Sources

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
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<tbody>
<tr>
<td>Ad-hoc Datasets</td>
<td>Querying, Mining &amp; Exploration</td>
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<tr>
<td>T2</td>
<td>Controlled Data Modification</td>
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</table>

## Decision-Making

<table>
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<th>Process</th>
<th>Description</th>
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<tbody>
<tr>
<td>Exploration &amp; Discovery</td>
<td>Data Governance &amp; Stewardship</td>
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<tr>
<td>Reports &amp; Dashboards</td>
<td>Security &amp; Access Control</td>
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</table>

## Application Domains

- MASH Report
- Flight Surgeon Dashboard
- Content Analytics
- Machine Learning
- Data Catalog & Search
- Portfolio Analytics
- Portfolio Analytics
1. R + 1yr: come back to preflight baseline?
   a. Effects post flight?
   b. Back to Pre-flight baseline?

2. Astronaut Career: come back to pre-selection baseline?
   a. Effects on career?
   b. Can they fly again?

3. Lifetime
   a. Effects on lifetime risk?
   b. Will they have problems later in life?

2013 Mortality Multiple Cause Micro-data Files
http://www.cdc.gov/nchs/data_access/Vitalstatsonline.htm
Long Term Health Recommendations

We do not understand LTH effects sufficiently to advise interventions

Long Term Health Definitions

1. R + 1yr
2. Astronaut Career
3. Lifetime

- Generate a list of conditions with potential LTH consequences
- LSAH/HRP joint project to define relevant clinical and research data collection to monitor through program evolution
- Construct a Medical Data Architecture to support data collection and analysis
- Occupational Health to set triggers for intervening on data trends that are concerning
- Periodic re-evaluation of data collected to narrow or expand scope as more is learned about long term health effects
Three Sources of Information

- Clinical Medical
- Human Performance
- Research
HHP System Development

Science Focus  Engineering Focus  System Integration

SHFH  BHP  HHC  ExMC  SR

ISS Testing  Orion  Proving Ground  Mars
Systems Testing and Development

Exploration Medical System Analog Testing and Evaluation

EMSD

Analog 1

Version 1

Feedback and Improvement

Analog 2

Version 2

Analog 3

Version 3

Flight

Time

Notional
MDA Test Bed Roadmap

<table>
<thead>
<tr>
<th>Phase</th>
<th>Test Bed 1</th>
<th>Test Bed 2</th>
<th>Test Bed 3</th>
<th>Test Bed 4</th>
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<tbody>
<tr>
<td>Capability</td>
<td>• MDA System Definition</td>
<td>• MDA System Enhancements</td>
<td>• Multi-agent Data Mining</td>
<td>• Computed Clinical Diagnosis</td>
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<td>• Biomedical Device Integration Definition</td>
<td>• Biomedical Device Provisioning</td>
<td>• Computed Problem Solving</td>
<td>• Augmented Intelligence</td>
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<td>• Image Analysis</td>
<td>• Knowledge Base</td>
<td>• Semantic Relations Network</td>
<td>• Remote Data Asset Synchronization</td>
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<td>• Data Mining</td>
<td>• Improved UI</td>
<td>• Optimized UI</td>
<td>• FDIR</td>
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<tr>
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<td>• Basic UI</td>
<td>• Interface Engine</td>
<td>• Ground System Int.</td>
<td>• Analog Test Prep</td>
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<tr>
<td>Medical Resources</td>
<td>• Astroskin</td>
<td>• Medical Consumables Tracking</td>
<td>• BHP appliances, apps and data</td>
<td>• Vehicle Resources Oxygen, Medical Suction</td>
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<td>• EKG</td>
<td>• Flexible Ultrasound</td>
<td>• HHC appliance apps and data</td>
<td>• Vehicle subsystem integration (ECLSS, Avionics, Power, Thermal)</td>
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<tr>
<td></td>
<td>• Dose Tracker</td>
<td>• ELA</td>
<td>• Ground System Data Analytics Platform</td>
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</tbody>
</table>
Integrated System Testing

Benchtop

Integrated System

Analog

Medical Appliances (H/W and S/W products)

ITERATE

NASA Internal

External

IPAS

Integrated Sims

Ground System

Hestia

HERA

Aquarius

Smart Pods

DOD

Antarctica

Independent Evaluation of System

(Likely tied to IPAS)
Backup
Human Health and Performance System Block Diagram

Flight System

In-Flight Health Data System
- Data Repository
- Data Analytics & Decision Support

Medical Appliances System
- FUS
- EKG
- ...

In-Flight Health Maintenance System
- Exercise System
- Behavioral Health System
- Food System

In-Flight Health and Performance Monitoring Data System
- Biomarkers System
- Physiological Data Stream System

Vehicle & Habitat Environment Management System

Mission Task Performance Support System

Ground System

Ground Health Data System

Pre- and Post-Flight Medical Appliances

Ground Health Maintenance System

Ground Health and Performance Monitoring Data System

ExMC scope
Interfaces within HH&P
Interfaces external to HH&P

Crew as Caregiver
Crew as Explorer or Patient

FSW, Telecom, Avionics, Power, Structures, ECLSS, EVA Systems, Robotic Assets, GNC, 
Researcher, Analyst, MCC, ASCR, FOD Trainer, Flight Surgeon
Medical Decision Support System (MDSS)

A knowledge system designed to use patient medical data and medical knowledge to generate case-specific assessment and recommendations to help medical staff make medical decisions.
Hybrid Approach for Implementation

- Knowledge based
  - Use of knowledge bases
  - Inference engine
  - Decisions based on rules

- Non-knowledge based
  - Machine learning
  - Neural Networks (ANN/CNN) and algorithms
  - Derive knowledge from patient data
  - Learn from decision trees