Team 10
MagiChess
Jack Deguglielmo, Samantha Klein, Weishan Li, Sai Thuta Kyaw
Advisor: Shira Epstein
Meet the team

Jack Deguglielmo
Computer Engineer

Samantha Klein
Electrical Engineer

Sai Thuta Kyaw
Electrical Engineer

Weishan Li
Computer Engineer

Shira Epstein
Faculty Team Advisor
Problem Statement

For centuries, the game of chess has been played by two players sitting across a chessboard. The advent of digital technology in the last decades has brought virtual chess to computers and mobile phones and for the first time, this has allowed players to be anywhere across the world.

Digital chess lacks:
- A physical aspect/satisfaction of seeing and moving your own pieces

Physical chess lacks:
- Ability to play from anywhere and with anyone
Our Solution

We’ve decided to close the gap between physical and digital chess. To do this, we plan to create a chess board that allows users to play with an AI or a remote human opponent.

Plan:

- Sense location of chess pieces on the board
- Interface with LiChess server
- Automate piece moving
Preliminary System Specifications (Design-agnostic)

- Mechanically move a piece to destination cell
- Remove/replace a piece to/from game board
- Provide visual feedback
  - Game setup, tutorial
  - Game announcements
  - Where pieces can move after picked up
- Provide audio feedback
  - Notification alerts
- Play versus remote opponent
- Playback previous games
- Includes buffer zone to store captured pieces
- Topple the King after checkmate
Preliminary System Specifications (Quantitative)

- Total system dimensions: no larger than 33.5 in x 28 in x 8in (85cm*68cm*20cm)
- Speed of XY plotter: 4-5 cm/s
  - Max time for a move: 15s, x2 for capture and transport
  - Average time for a piece to move: 7.5s
- Weight: Under 25lbs
Proposed MDR Deliverables (From PDR)

- LiChess integration with Raspberry Pi (initiate games, execute moves, etc.)
- GUI prototype for Raspberry Pi touch display
- Raspberry Pi outputting digital communication protocols
- Assembly and movement of XY plotter (gantry)
- Results from RFID multiplexing / Hall Effect sensor testing
  - Decision on which sensing technique to use
MDR Deliverables: Sensing Technique

- **Initial Testing**
  - Magnet Sizes
  - Sensing Methods
  - RFID Test
  - Electromagnet

- **Final Product**
- **Testbench**
  - Mimics Gantry (EM moving on a plane)
  - Height Adjustable
  - Controls Electromagnet
  - Sensors and Display

Chess Pieces Sensing Report

Three different proposed methods of chess pieces sensing:

- **Method 1**: Use multiplexed RFID antennas across 64 cells.

- **Method 2**: Use six different strength magnets with different poles to identify pieces.

- **Method 3**: Use magnets to sense occupied cells and a single RFID reader to identify pieces.
1. RFID Only Sensing Solution

- Multiplexing RFID Antennas with single RFID Reader Chip
  - Research based on RFID Multiplexer Example from Texas Instrument
  - Ordered the Parts and Breakout Boards
  - Mismatched Breakout Boards for RF Switch
    - Same package (QFN16) different size
    - Breakout board datasheet incomplete

- 64 RFID Readers on single TWI interface
  - AT88RF1354 Atmel TWI RFID Reader Chip
  - Two possible addressing (need at least 8)
2. Hall Effect Sensor Only

Method 2: Use six different strength magnets with different poles to identify pieces.

- Know what physical properties of the magnet the sensor can measure
- Analog Hall Sensor SS49E
  - Magnetic Flux Density (Gauss) in terms of Voltage
How to vary reading on Analog Hall Sensor?

- Will Stacking Magnets Increase Reading on Sensor?
How to vary reading on Analog Hall Sensor?

- Changing the position varies the reading on the Analog Hall Sensor
- Varied the height of the magnet relative to the base
- The Magnetic Flux Density changes with Altitude.
- Tolerance for pieces off-centered is acceptable
- Not the best fit
  - Need 6 different altitudes
  - The higher the altitude, the harder the electromagnet to attract
3. Hall Sensor & RFID Hybrid

- Hall Sensor for fast scanning of ChessBoard
  - Monitor movements of Chess Pieces by user
  - Fast Scanning - Up to 1MHz
  - Software keeps track of chess piece location

- RFID Tags for verification
  - RFID reading works with electromagnet turned on
  - Selectively verify chess pieces
    - Before every game
    - Before and after each move
Sam’s Individual Report: MDR deliverable

MDR Deliverable:

- Results of Multiplexing tests

Result of testing (In collaboration with Sai):

- Hybrid method
  - 64 multiplexed hall sensors
  - One RFID reader and antenna for the electromagnet
Sam’s Individual Report pt. 2: Post PDR Accomplishments

RC522:
- Got one working (tested w/ LED)

I2C bus:
- Considered creating a bus with RFID readers rather than multiplexing
- Began drafting the bus

Hall Effect Sensors:
- Got one working (tested w/ LED)
- Multiplexed 4 of them
Sam’s Individual Report: I2C bus

- **Fast Mode**
  - $C_b \leq 400 \text{ pF}$
  - $f_{CLK} \leq 400 \text{ kHz}$
  - $t_{\text{rise}} \leq 300 \text{ ns}$

- **Pull Up Resistor:**
  - $R_{\text{max}} = \frac{t_{\text{rise}}}{C_b} = \frac{300\text{ns}}{C_b}$
  - $R_{\text{min}} = \frac{(V_{CC} - V_{OL(\text{max})})}{I_{OL}} = \frac{(3.3 - 0.4\text{V})}{0.3 \text{ mA}} = 0.966 \text{ kΩ}$

- **Bus Capacitance**
  - If $C_b \geq 400 \text{ pF}$, a buffer must be added
  - Atmega328: 10 pF
  - Reader (AT88RF1354-ZU): ??
    - Only 2 possible address locations

I2C bus with 8 readers and no buffer
Sam’s Individual Report: Demo!

Hall Sensor Multiplexing

- Used the SN54HC157 from Texas Instruments
  - Quadruple 2-1 Mux
- Multiplexed 4 hall effect sensors
  - Used 2 of the 4 2-1 muxes on the IC
  - Verified using the Arduino serial monitor

Software - Video Demonstration
Graphical User Interface

Python `tkinter` library
- Frames
- Widgets
Game Window

Python **pygame** library
- Draw objects
- Load images
- Update and reflect local gamestate
Event Stream, Game Stream

Python **multiprocessing** library
- Communication
- Event Stream
- Game Stream
LiChess API

Python `requests` library

- LiChess interface file
  - Create streams
  - Make challenges
  - Make moves

Example challenge request:

```python
r = requests.post('https://lichess.org/api/challenge/', username, json_configurations, headers={'Authorization': f'Bearer {api_key}'}
print(r.content)
if r.status_code == 200:
    # response message from challenge request to LiChess
    json_response = r.json()
    gameid = json_response['challenge']['id']
    return gameid
else:
    return 0
```

Example game stream request response:

```
{
    "type": "gameState",
    "moves": "e2e4 c7c5 f2f4 d/d6 glf3 b8c6 f1c4 g8f6 d2d3 g7g6 e1g1 f8g7 blc3",
    "wtime": 7598040,
    "btime": 8395220,
    "winc": 10000,
    "hinc": 10000,
    "status": "started"
},
```
Example challenge request response:

```json
{
    "id": "VU0nyvsw",
    "url": "https://lichess.org/VU0nyvsw",
    "color": "random",
    "direction": "out",
    "timeControl": {
        "increment": 2,
        "limit": 300,
        "show": "5+2",
        "type": "clock"
    },
    "variant": {
        "key": "standard",
        "name": "Standard",
        "short": "Std"
    },
    "challenger": {
        "id": "thibot",
        "name": "thibot",
        "online": true,
        "provisional": false,
        "rating": 1940,
        "title": "BOT"
    },
    "destUser": {
        "id": "leelachess",
        "name": "LeelaChess",
        "online": true,
        "provisional": true,
        "rating": 2670,
        "title": "BOT"
    }
}
```

- "perf": {
  "icon": ";",
  "name": "Correspondence"
},
  "rated": true,
  "speed": "blitz",
  "status": "created"
}
Local Gamestate

- GameState object with `self.board`
- If user is white side:
  - A >> [-][0], H >> [-][7]
  - 1 >> [7][-], 7 >> [0][-]
- If user is black side:
  - A >> [-][7], H >> [7][-]
  - 1 >> [0][-], 7 >> [-][0]
GUI / Game Demo
Updates on Chess Piece Path Planning

- Progress Updates
  - Developed position map structure
  - Straightline heuristic implementation
  - Transitioned to greedy best first search

Path Planning Sequence
1. Translation of gamestate to position map
2. Heuristic calculation for each position state
3. Greedy Best First Search
4. UART Transmission of path to 328P

Path Planning the Chess Pieces

Why A* Search?
1. Completeness
2. Optimality
3. Best-First Search
4. Allows for diagonal movements

Heuristic Function:
- number of moves from solution

\[ f(n) = g(n) + h(n) \]
Translation of Gamestate

8x8 Gamestate with Buffers

Position Map

17 by 27 Matrix of Positions

Traversing Position
Piece Occupying Position
Translation of Gamestate (python)

8x8 Gamestate

```
["bR", "bH", "bB", "bQ", "bK", "bB", "bH", "bR"]
["--", "--", "--", "--", "--", "--", "--", "--"]
["--", "--", "--", "--", "--", "--", "--", "--"]
["--", "--", "--", "--", "--", "--", "--", "--"]
["--", "--", "--", "--", "--", "--", "--", "--"]
["wP", "wP", "wP", "wP", "wP", "wP", "wP", "wP"]
["wR", "wH", "wB", "wQ", "wK", "wB", "wH", "wR"]
```

Position Map
Heuristic Calculation

Straight Line Distance
Each position state’s heuristic is calculated manually using the distance formula relative to the goal state

$$\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

```python
straightLineDist = math.sqrt(math.pow(endPos[0]-i, 2) + math.pow(endPos[1]-j, 2))
posMap[i][j].heuristic = straightLineDist
```
Greedy Best First Implementation

- Why Greedy Best First over A*?
  - Better computational and space complexity
  - Yields similar results to A* (near optimal)
    - Paths are mostly straight lines with small variances
  - Overlaying our own constraints will be more manageable
    - Diagonal move constraints for magnets
Path Planning with UART Communication Demo
Raspberry Pi Digital Communication

MDR Deliverable: Raspberry Pi outputting digital communication protocols

- **Accomplishments:**
  - UART Communication with Atmega328P
  - I2C Communication with MCH23008
  - Live Demo of Path Transmission via UART
Evaluation Setup
MDR Deliverables: Gantry

Assembly and movement of XY Plotter Gantry

- Specifications
  - Dimensions 73 cm x 61cm
  - Working Area 62.9cm x 50.4cm
  - Gantry Speed
    - 4cm/s @ 60rpm
    - 5cm/s @ 75rpm
  - Stepper Motor
    - 200 steps/rev
    - 50 steps/cm

Link to code: https://github.com/degugj/lichessTesting/blob/master/arduino/
TEAM 10
GANTRY DEMO
MDR Deliverables

- Results from RFID multiplexing / Hall Effect sensor testing
  - Decision on which sensing technique to use
  - Working Subsystems
- LiChess integration with Raspberry Pi (initiate games, execute moves, etc.)
- GUI prototype for Raspberry Pi touch display
- Path Planning with Greedy BFS
- Raspberry Pi outputting digital communication protocols
- Assembly and movement of XY plotter (gantry)
Software Diagram - Game State

(A) gameStart, challengeDeclined, ...

(B) gameState, chatLine, ...
Hardware Plan for FPR

- Custom PCB to mount Hall Sensors underneath the ChessBoard
- 2 PCBs
  - Fast Scanning with Hall Sensor
  - Moving and Verification of Chess Pieces.
- PCBs should have
  - Microcontroller, Power Input, ICSP Headers, Connectors, Protection Circuit, Relevant Components
- Raspberry Pi, Stepper Motor Drivers, RFID Reader, H-Bridge
## Total Spendings

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<th>Items Purchased (Digikey)</th>
<th>Cost ($)</th>
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<tr>
<td>16QFN breakout board</td>
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<td>P25/20 Electromagnet</td>
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<td>13MHz NFC antenna (10)</td>
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| Total Spent                                 | 264.83   |
| Remaining                                   | 235.17   |
## Estimated Costs for Next Semester

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<td>Single Board Computer</td>
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<td>RFID Reader</td>
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<td>MCU</td>
<td>Arduino NANO</td>
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List of Software

- **ATmega328p code**
  - Gantry Control, Look up tables, reading rfid and digital communication
  - Fast Sensing, Signal Multiplexing, Mapping and digital communication
- **Python modules:**
  - GUI
  - Game / Event Stream
  - Pygame Game Window
  - LiChess Interface
  - GameState / Position Map
- **Supporting libraries:**
  - tkinter
  - multiprocessing
  - pygame
  - requests
Technical Responsibilities

Jack
- Raspberry Pi interface with 328Ps
- Board scanning and piece verification
- Autonomous game playback
- Altium Lead

Weishan
- Improving and refining GUI
- Interfacing between Raspberry Pi and 328Ps
- Autonomous game playback

Sam
- Hall Effect Sensor Multiplexing
- Budget Manager

Sai
- Movement of Chess Pieces
- RFID Verification
- Team Coordinator
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<th>Task</th>
<th>Team Member</th>
<th>Dec 6 - Dec 19</th>
<th>Dec 27 - Jan 16</th>
<th>Jan 17 - Jan 30</th>
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<th>Feb 7 - Feb 13</th>
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<td>Learn Altium</td>
<td>Design PCB</td>
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<td>Wooden Frame</td>
<td>Chess Board Cut and Etched</td>
<td>Finalize Chess Pieces</td>
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Gantt Chart Until CDR
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External Links

All Demo Videos Playlist

- https://www.youtube.com/playlist?list=PLN2cGbKly2ZLFxfQogWYSfkWECBJ7iLU9

Github Repo

- https://github.com/degugj/lichessTesting
Thank You
Justification of Atmega328P

- **Why?**
  - I/O Considerations
    - UART Pins
    - Stepper Motor Drivers
  - Familiarity
Path Planning Metrics

- **What is a heuristic?**
  - An estimated cost from node $n$ to a goal node

- **What is Greedy BFS?**
  - Greedy Best First Search is a search algorithm that expands nodes closest to the goal state, on the grounds that the closest nodes will return a solution quickly ($f(n) = h(n)$)
  - Time and space complexity?
    - Worst case: $O(b^m)$ where $m$ is the max depth of the tree
    - However, with our straight line distance and finite chess board, this will be reduced substantially