An investigation of AI methods for the facilitation of injury diagnosis and treatments

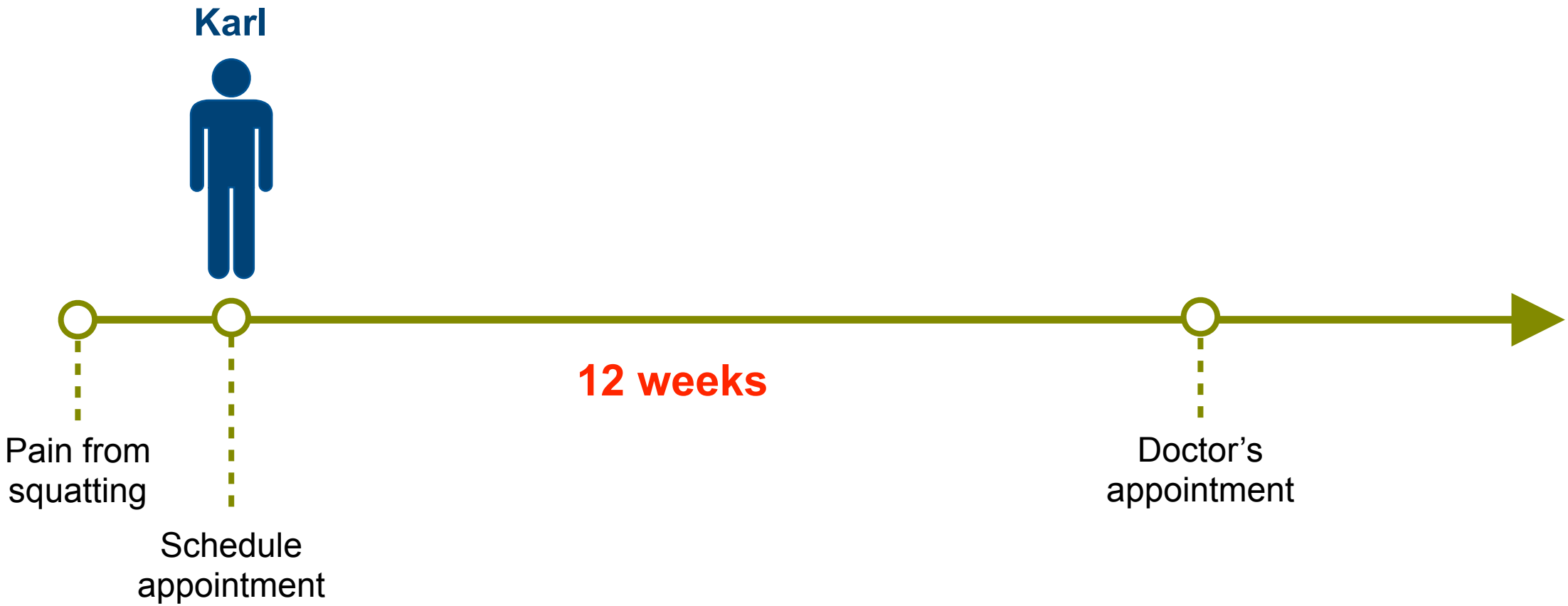
Bachelor Thesis Presentation

Aleksandra Topalova and Julian Kraus

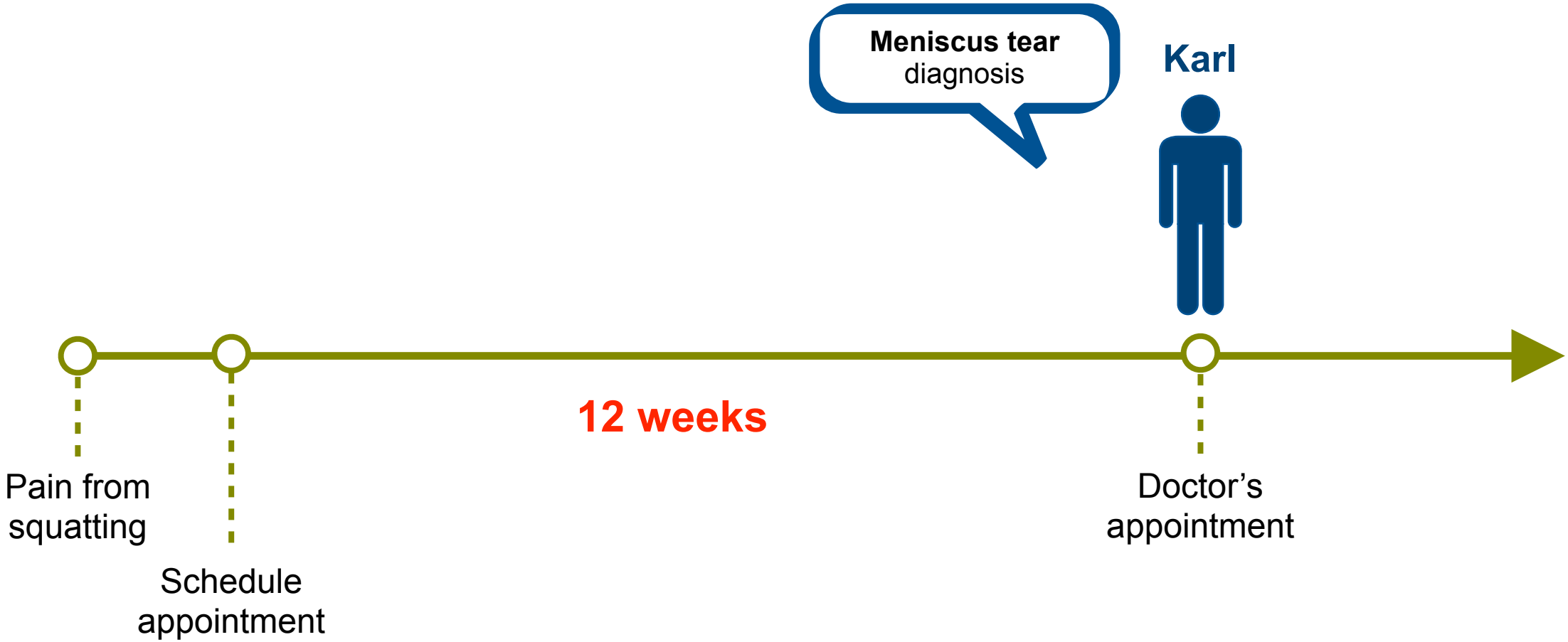
16.08.2024

The current situation

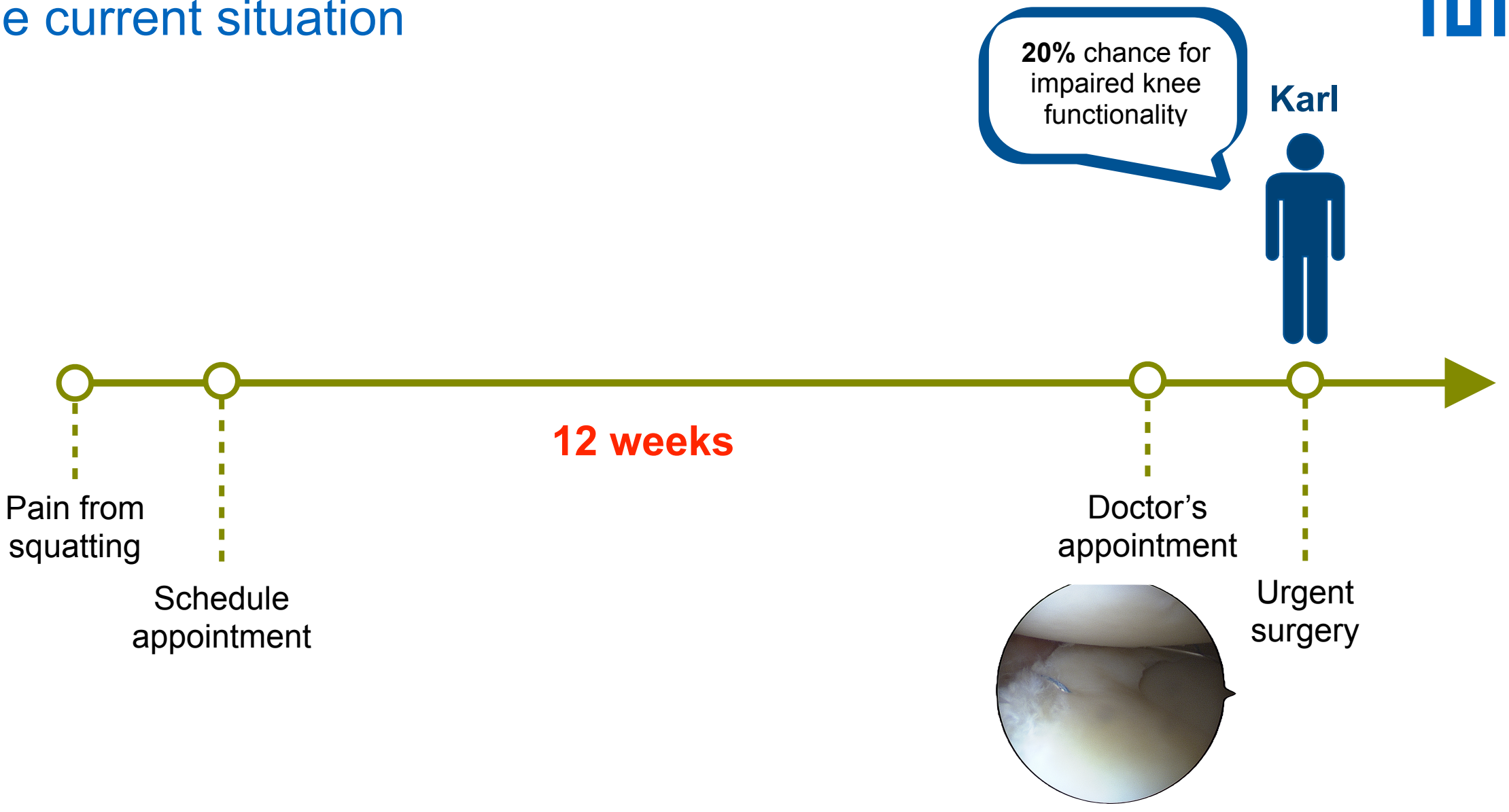
The current situation



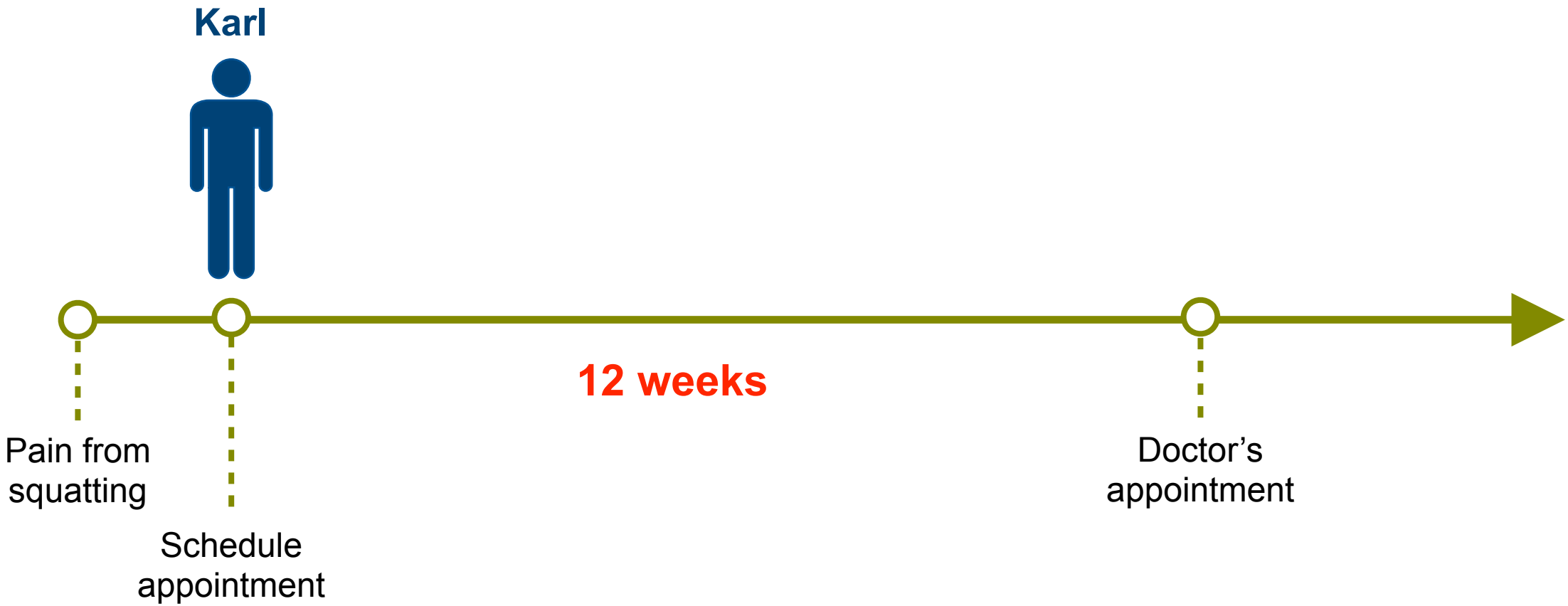
The current situation



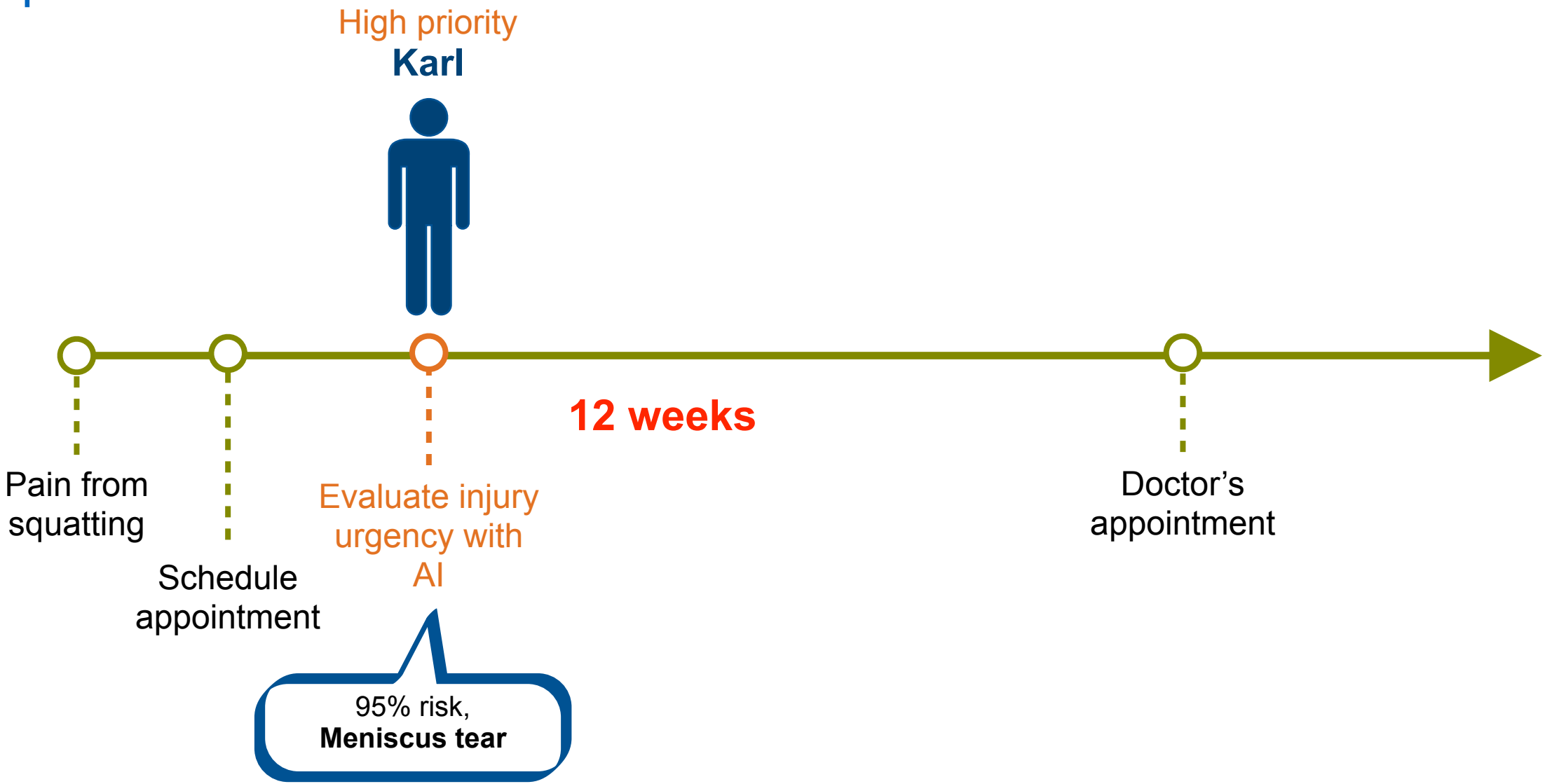
The current situation



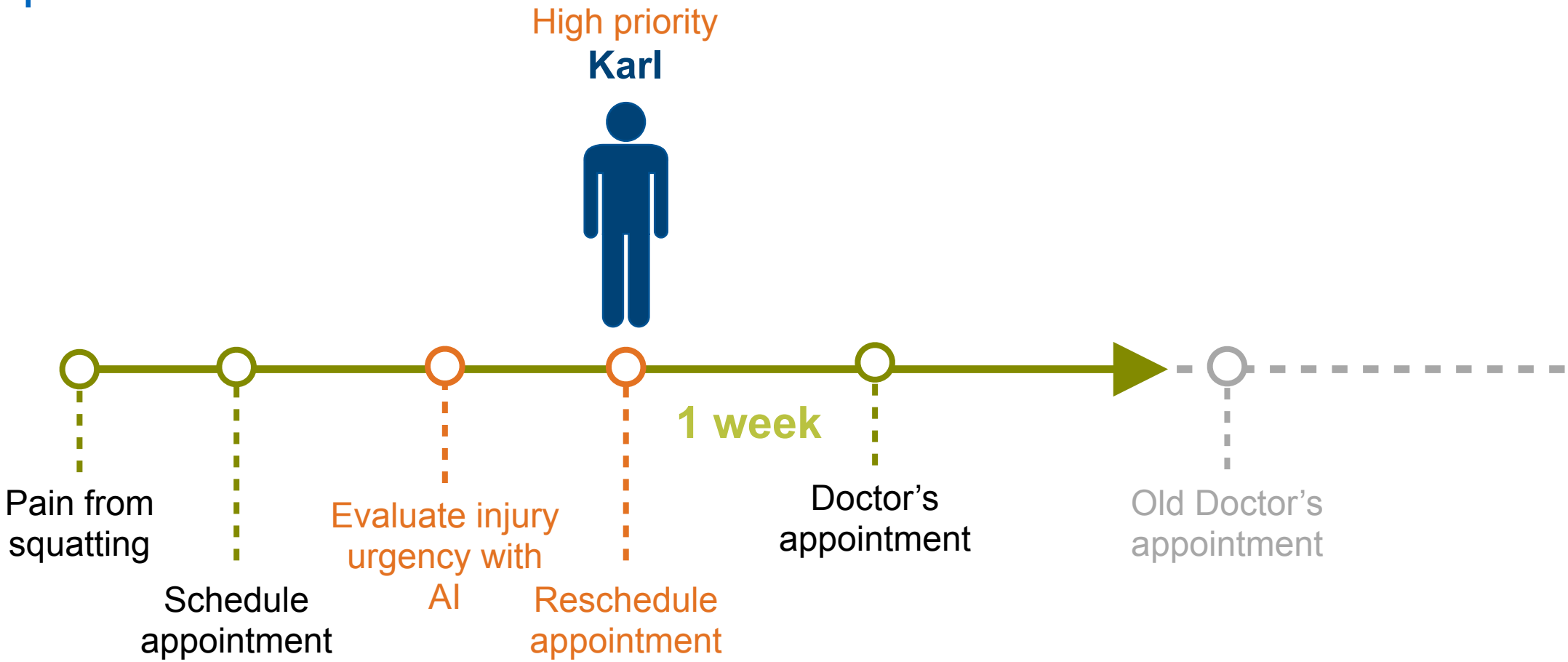
Proposed solution



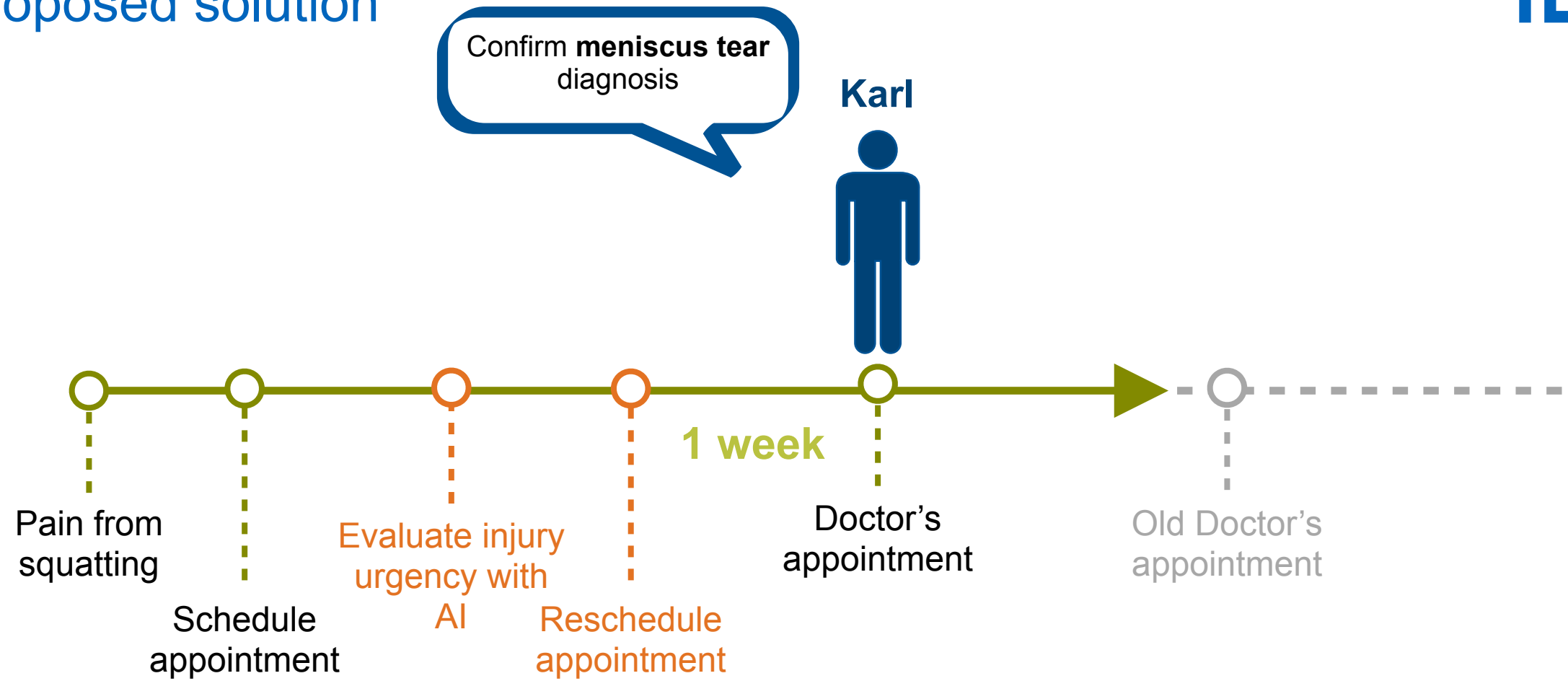
Proposed solution



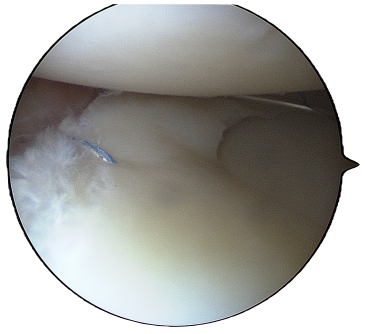
Proposed solution



Proposed solution



Proposed solution



Karl

<5% chance for impaired knee functionality

Pain from squatting

Schedule appointment

Evaluate injury urgency with AI

Reschedule appointment

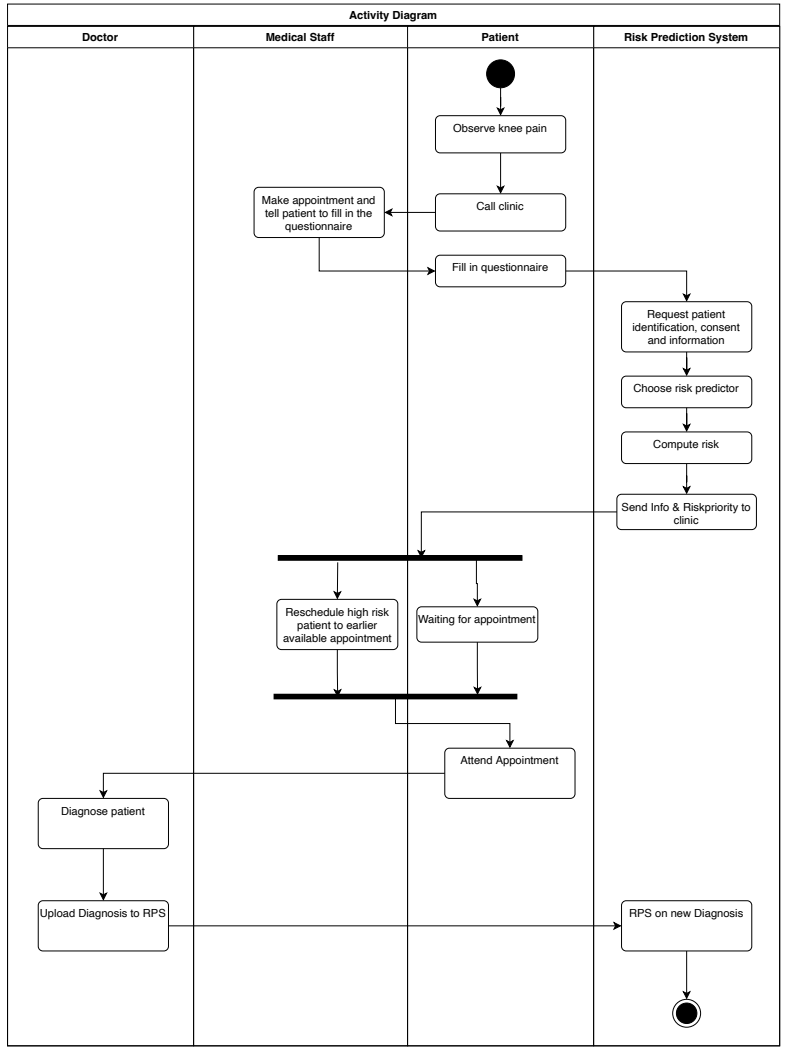
1 week

Doctor's appointment

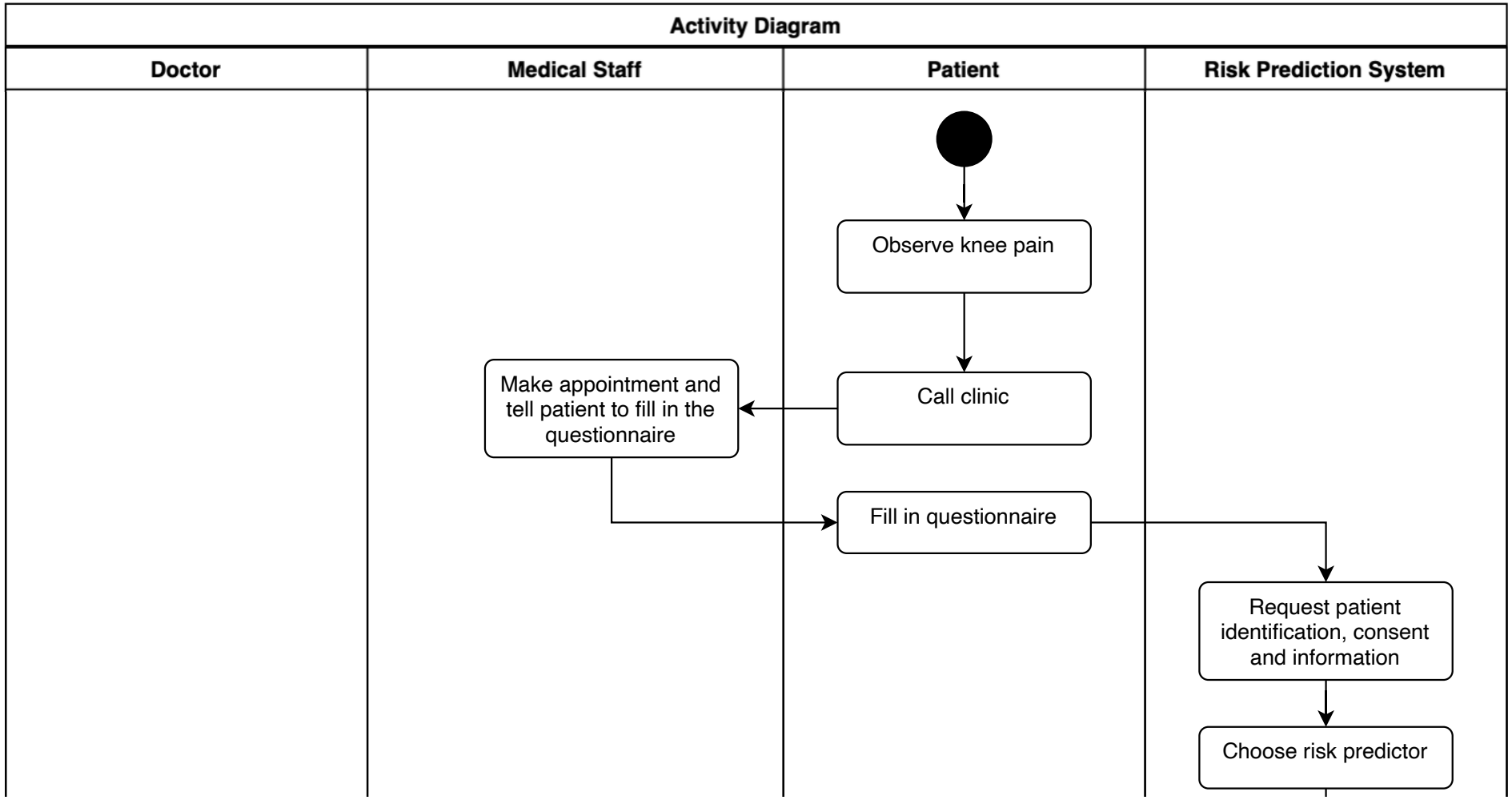
Urgent surgery

Old Doctor's appointment

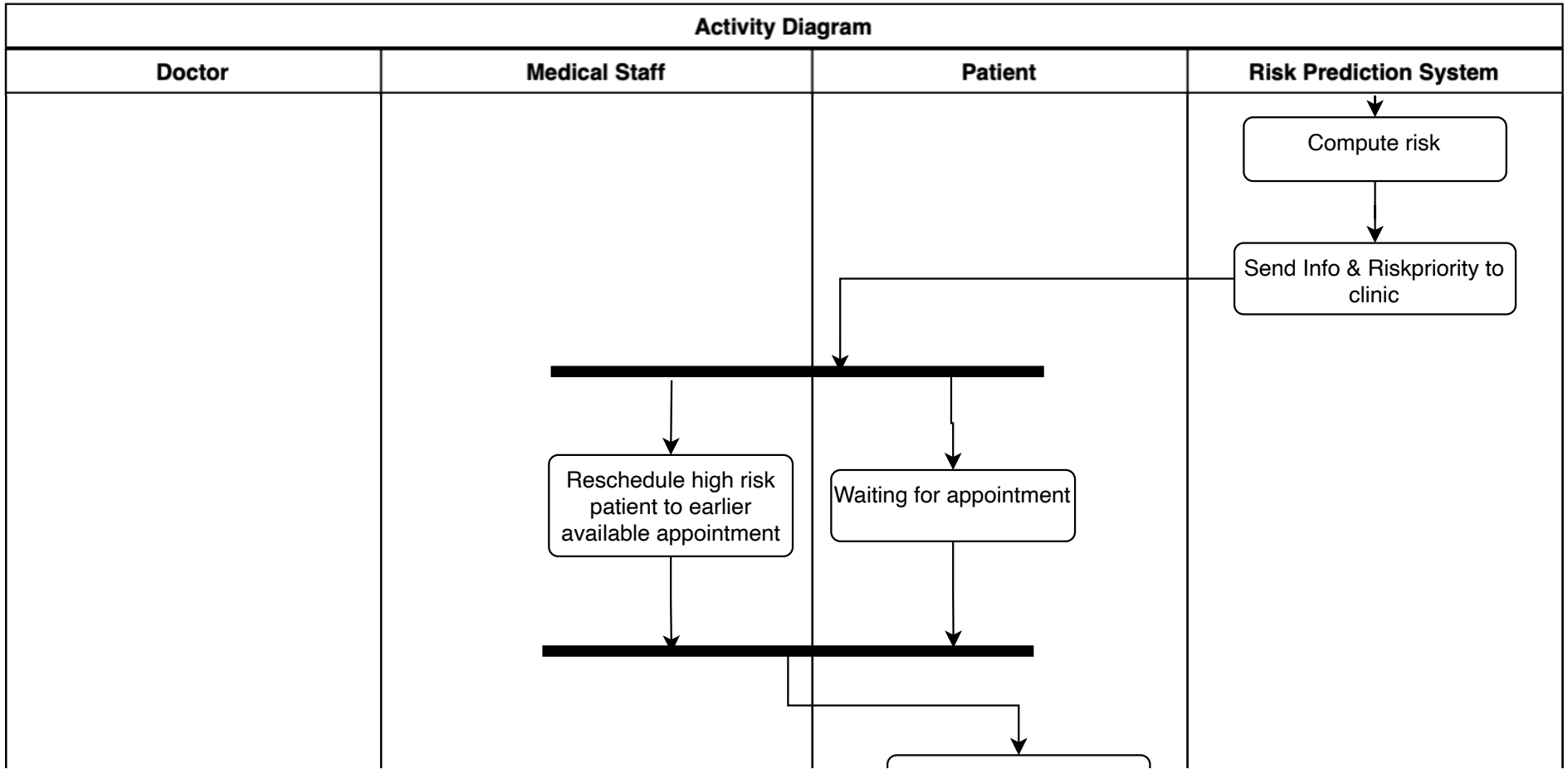
Dynamic Model



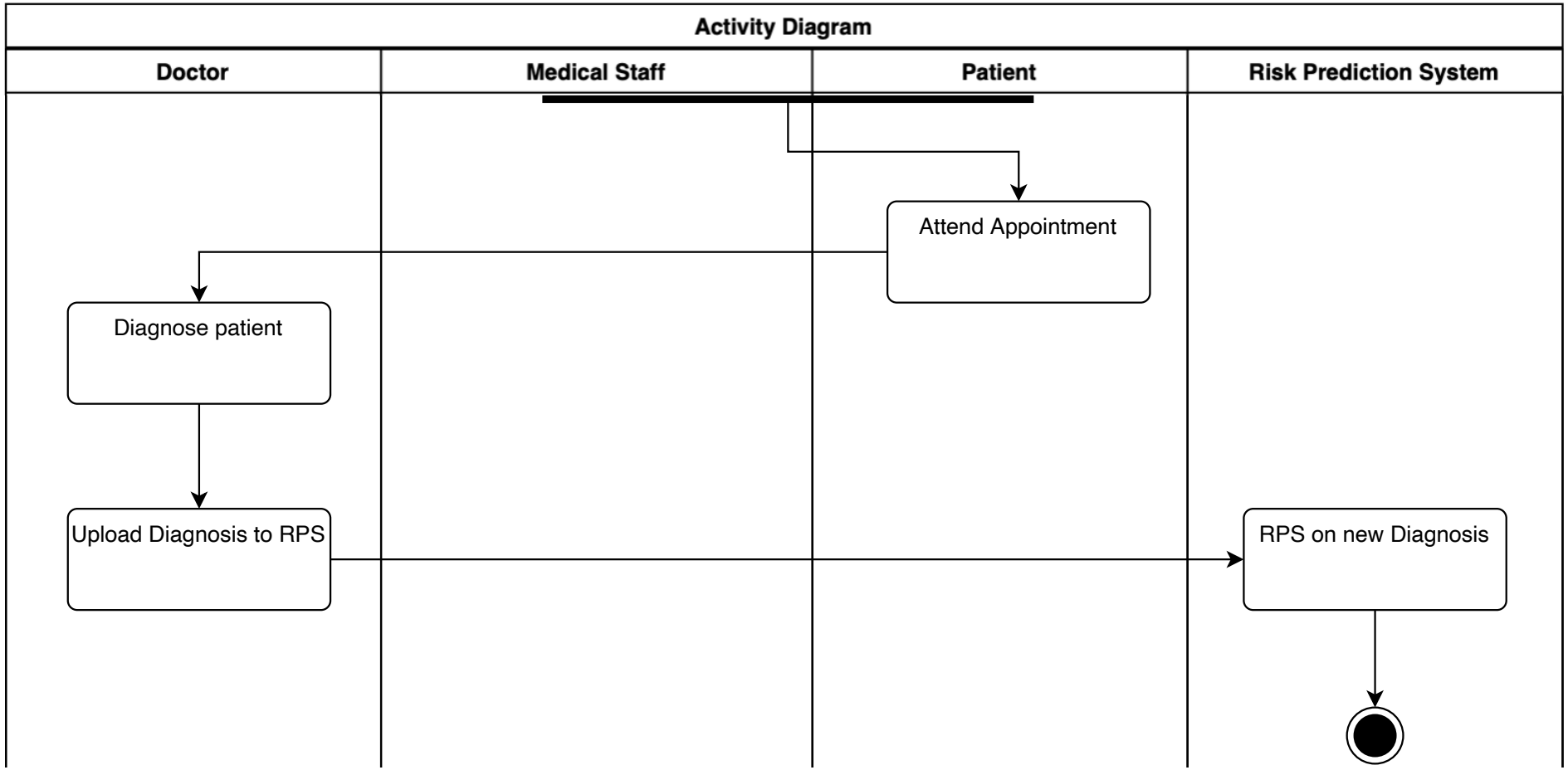
Dynamic Model



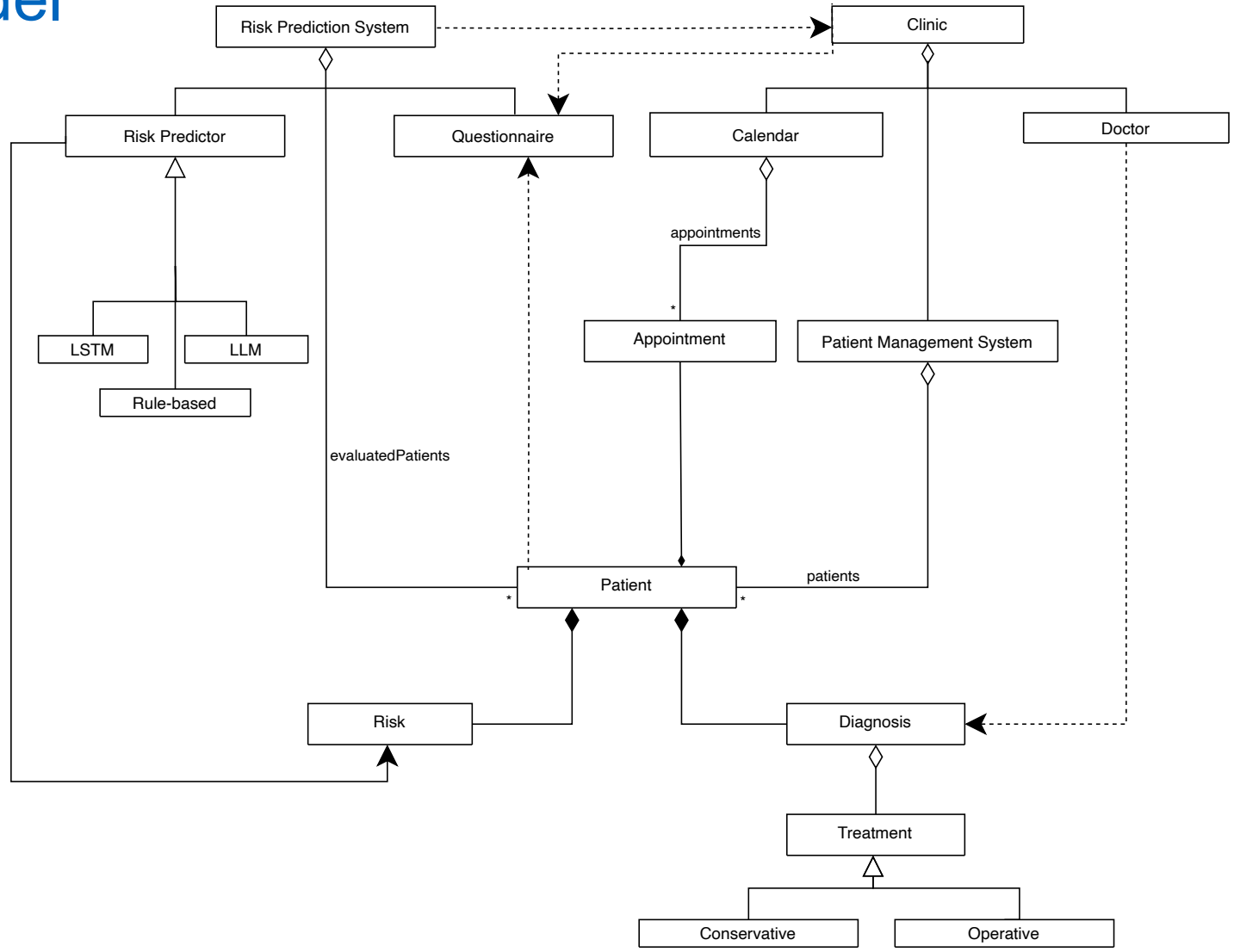
Dynamic Model



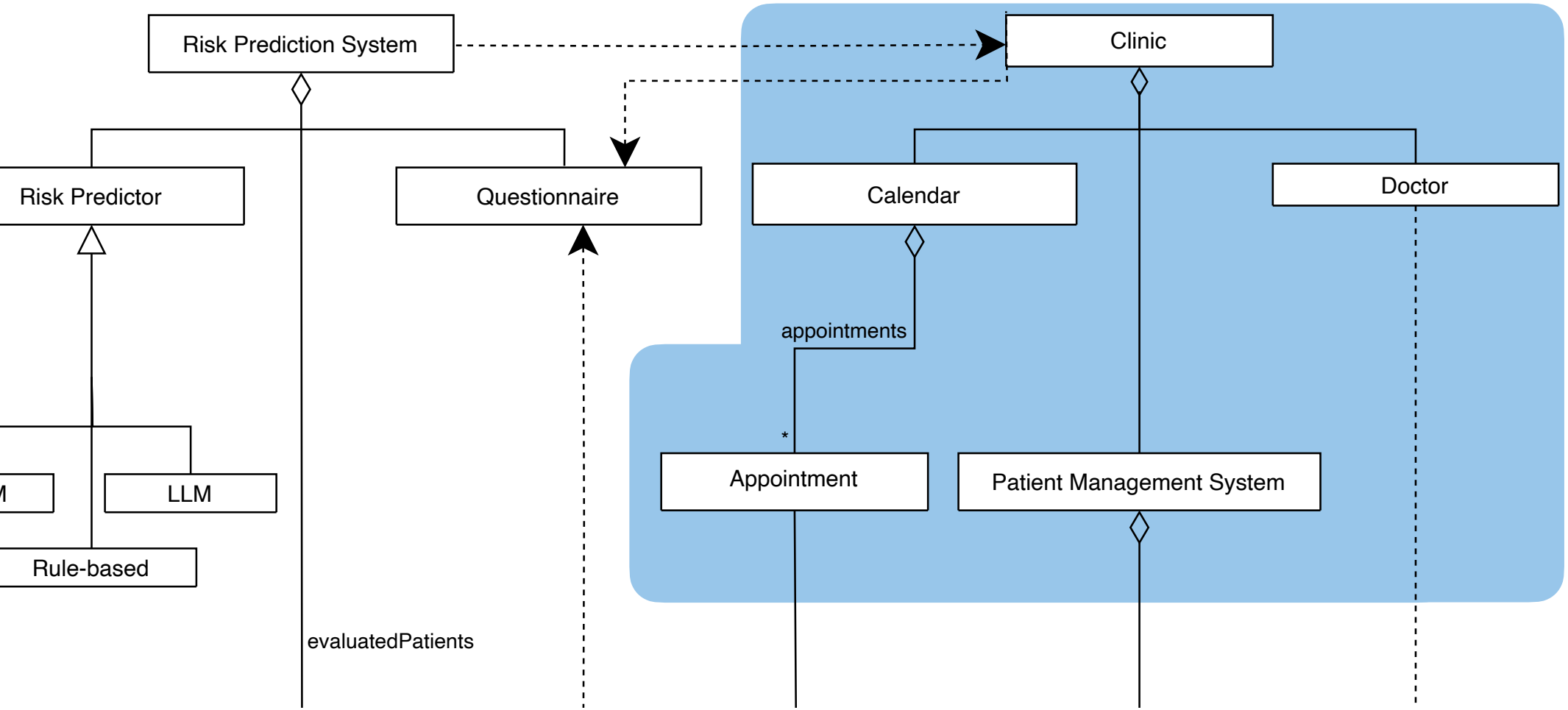
Dynamic Model



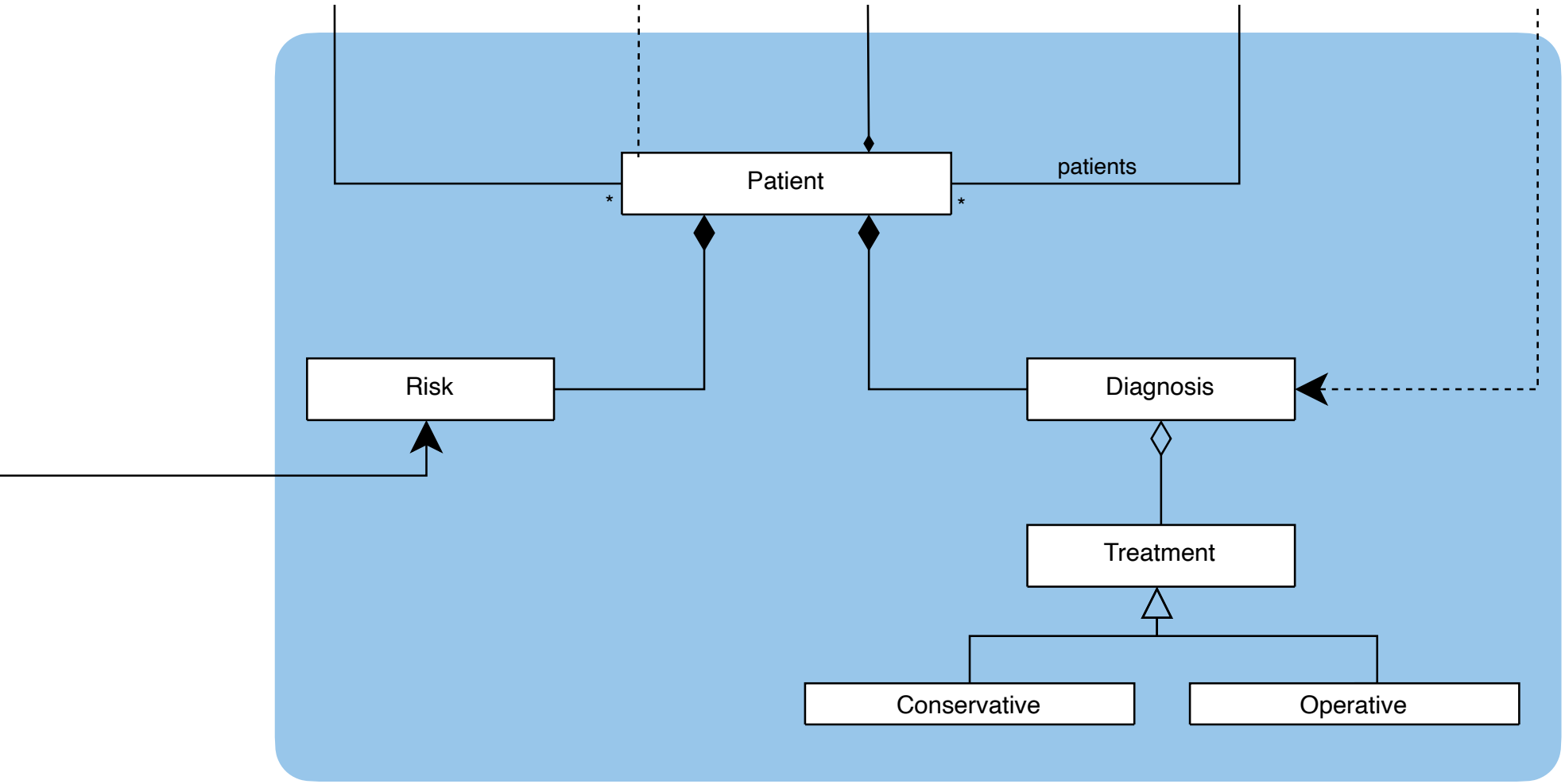
Analysis Object Model



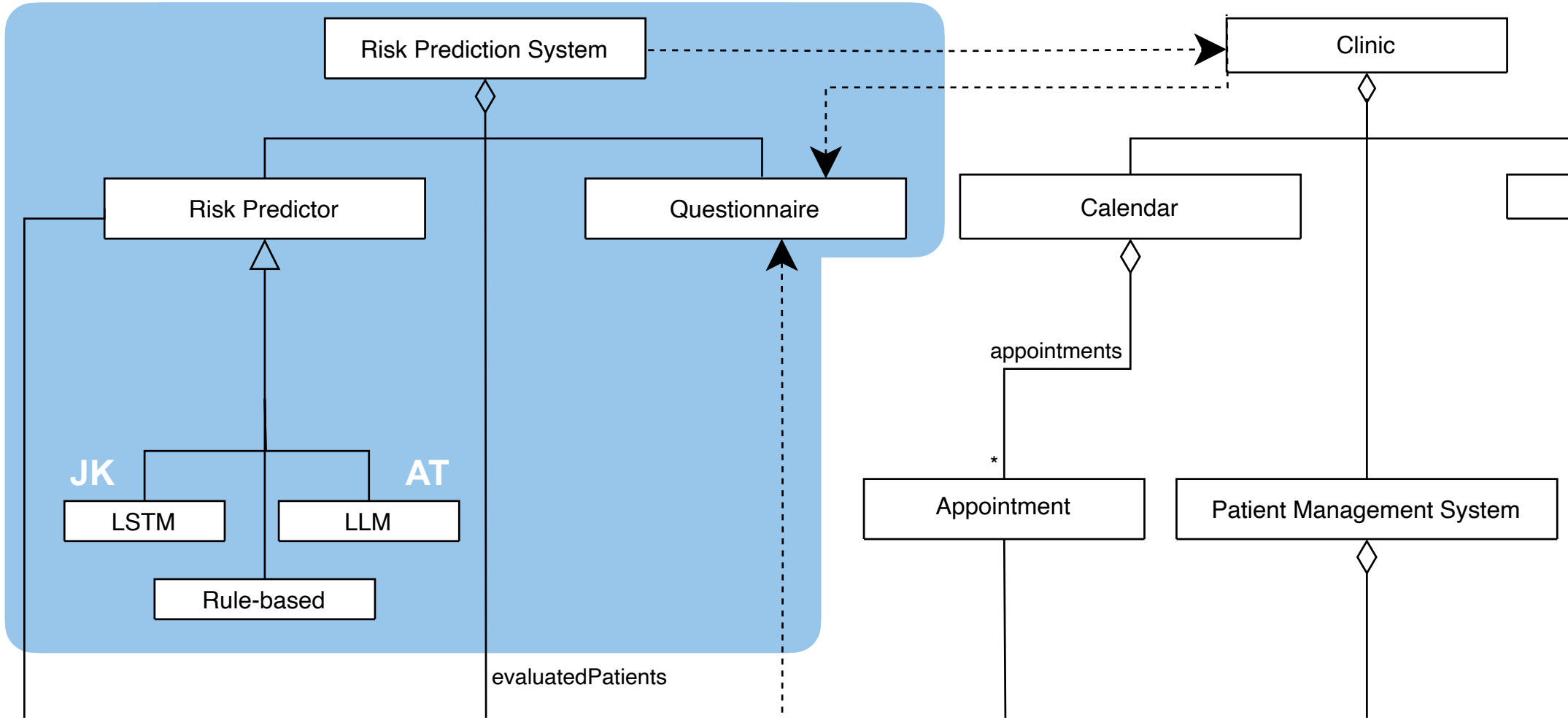
Analysis Object Model



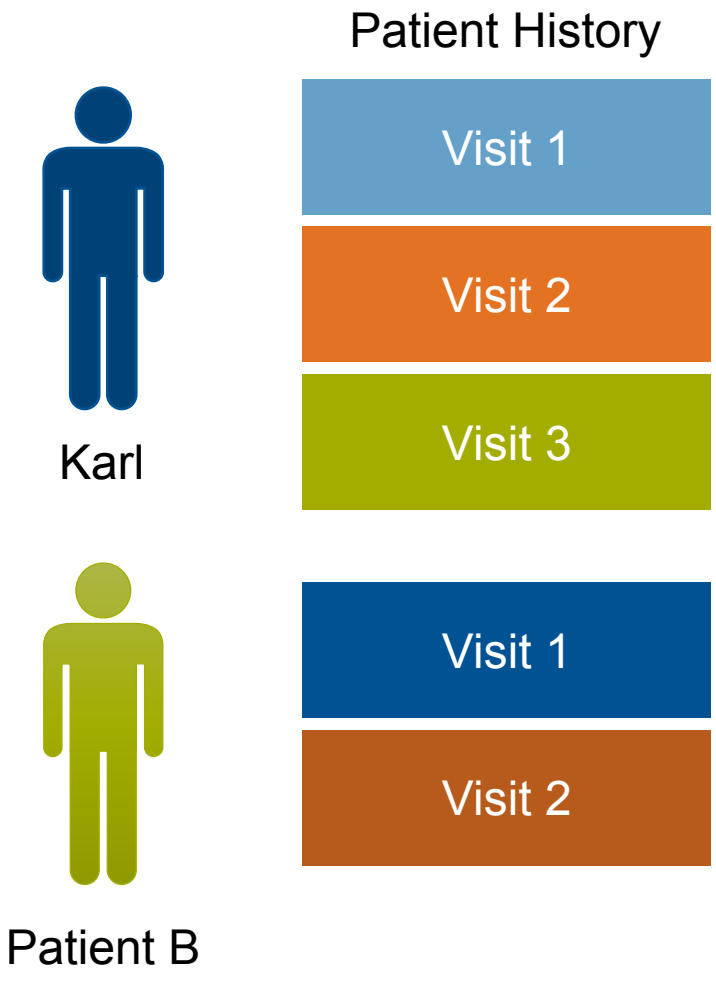
Analysis Object Model



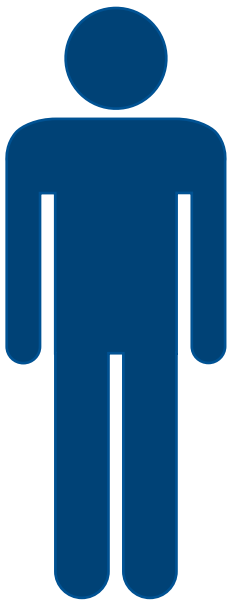
Analysis Object Model



Dataset Filtering



Dataset Filtering



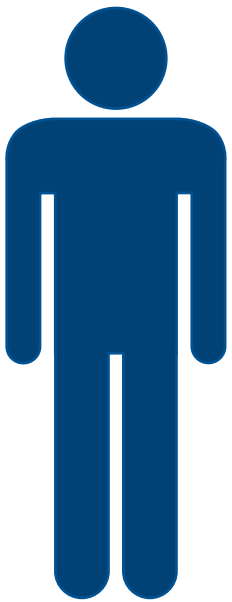
Karl

Visit 1

Visit 2

Visit 3

Dataset Filtering



Karl

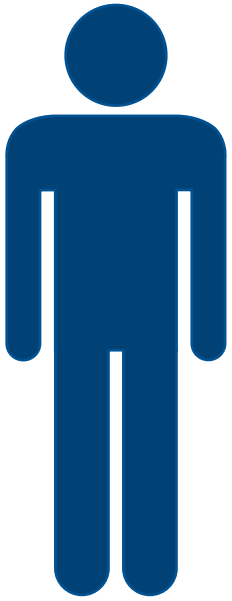
Visit 1

Visit 2

Visit 3

Group by visit clusters

Dataset Filtering



Karl

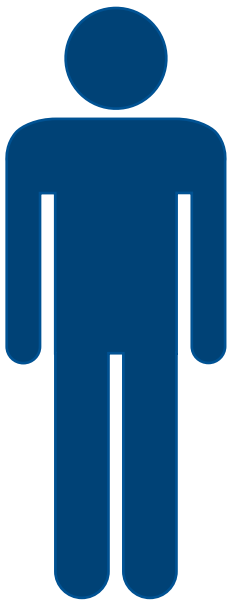
Injury

New Injury

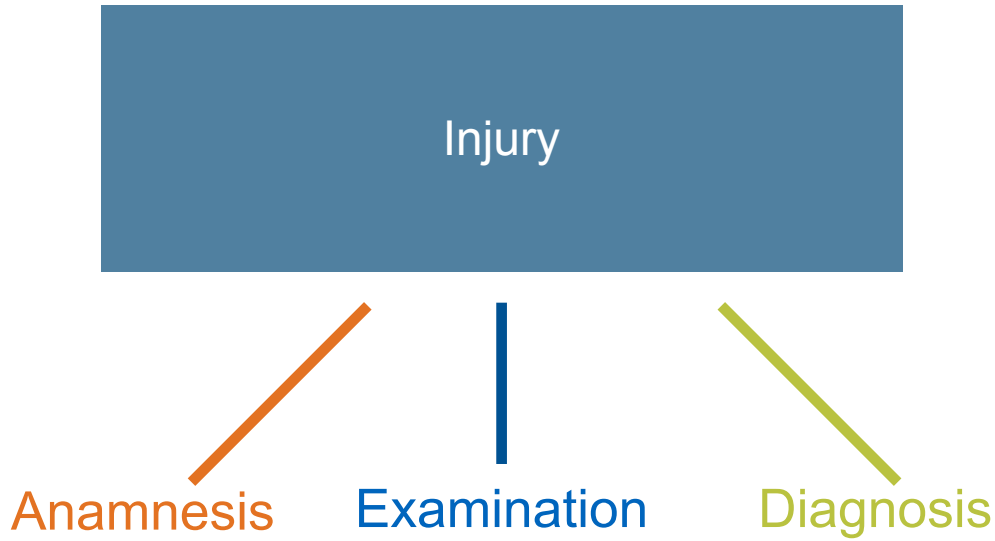
Group by visit clusters

Visit-Pause of 2 years → New Injury

Dataset Filtering



Karl



Data fields

Anamnesis	Diagnosis	Examination
• Patients' symptoms from their perspective • Patient history • Informal language	• ICD Code • Doctor description	
(…) Two years ago, there was a sprain of the medial ligament and a popping sensation in the knee when straightening the joint, followed by a period without symptoms. (…)	M23.3 Acute meniscal tear	

Diagnosis

Meniscus injuries

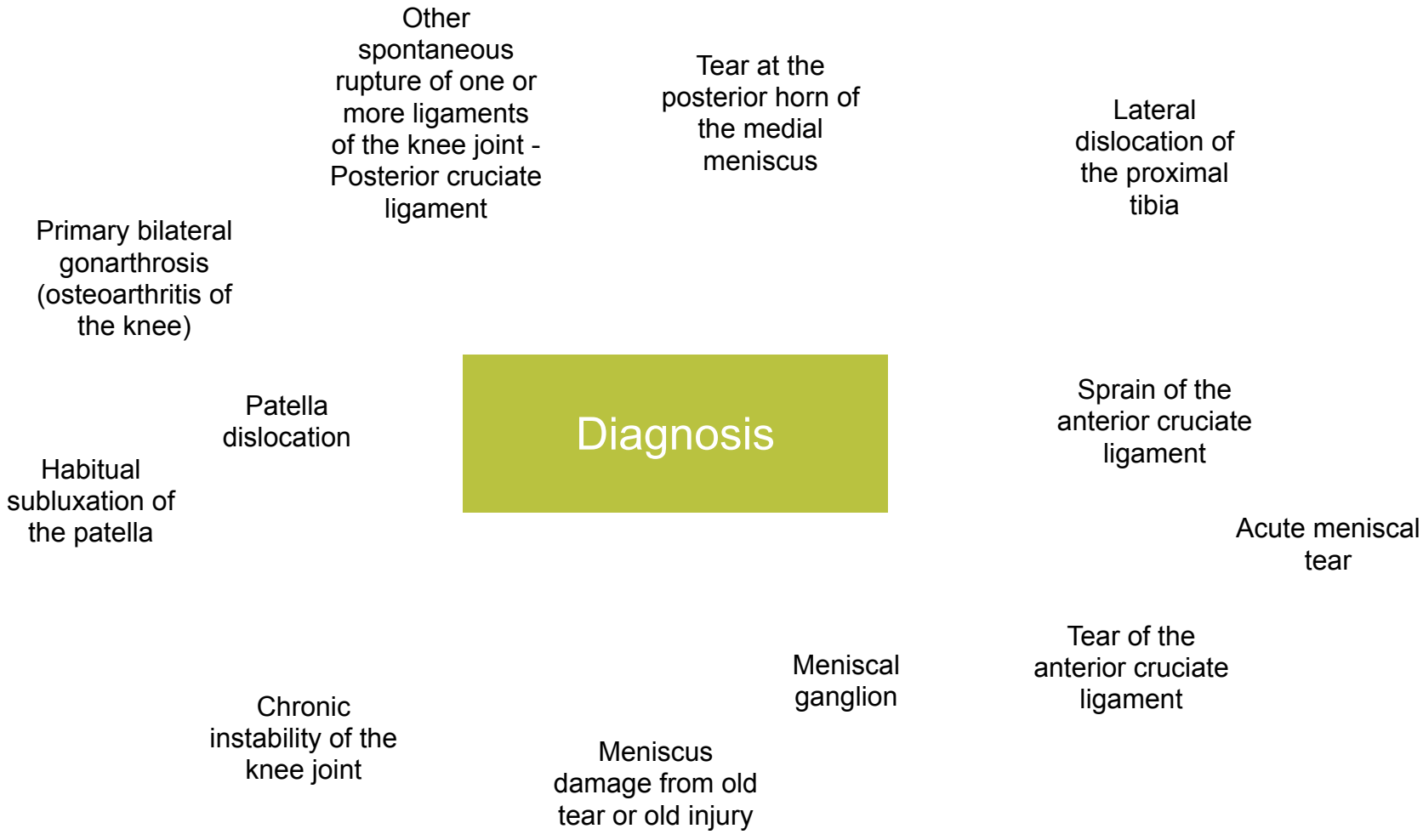
Patella injuries

Diagnosis

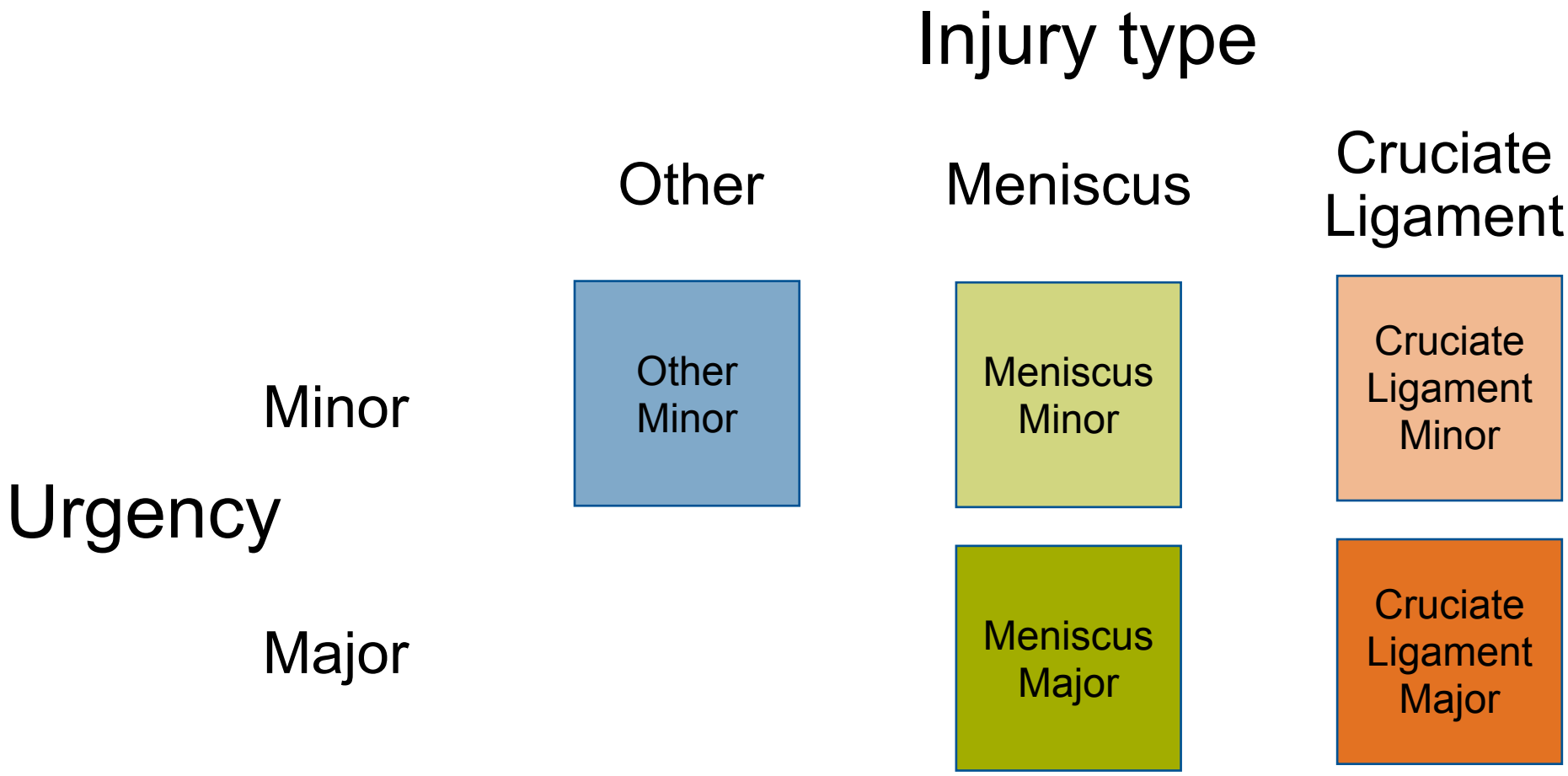
Cruciate ligament injuries

Arthrosis

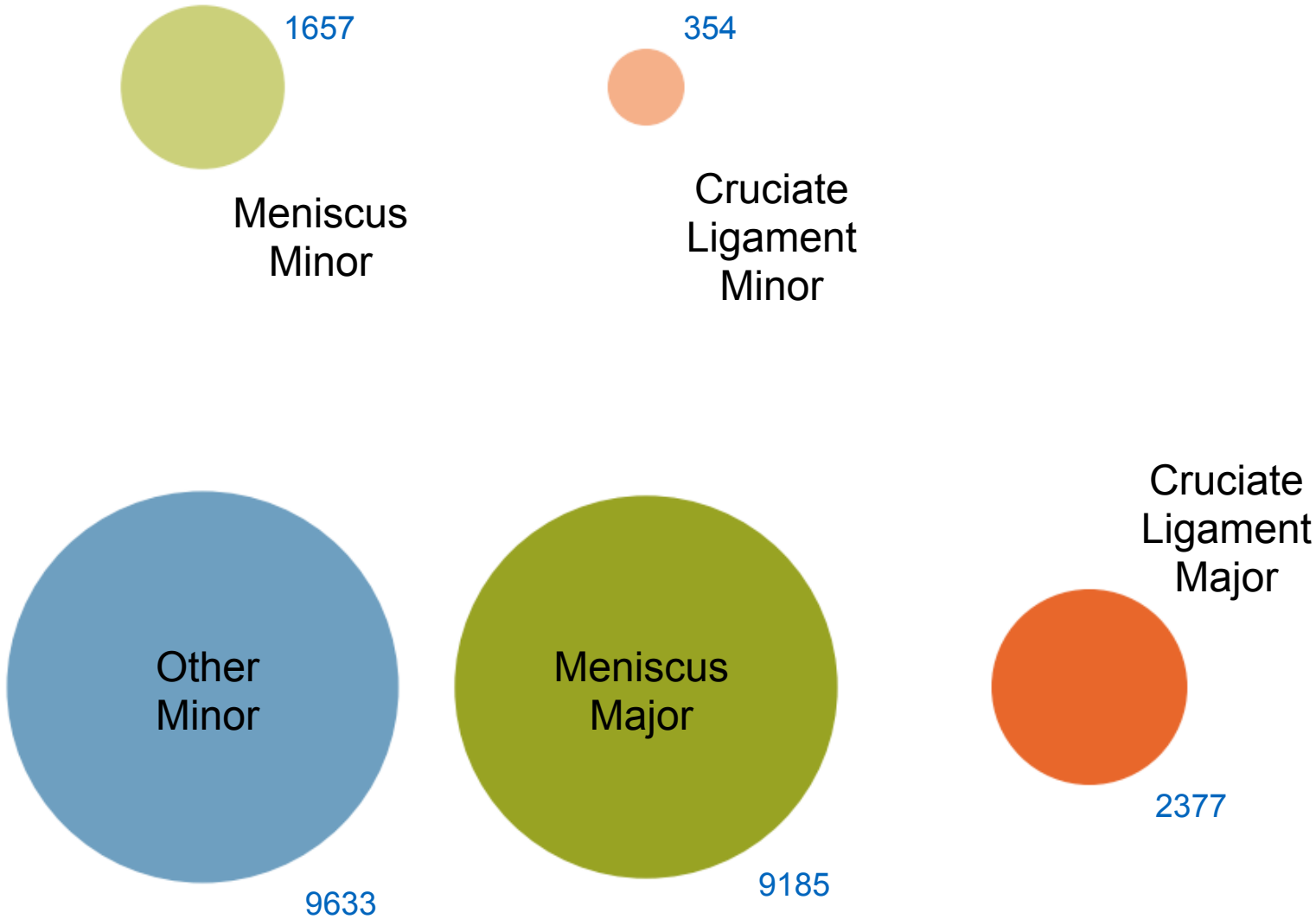
Diagnosis


Other spontaneous rupture of one or more ligaments of the knee joint - Posterior cruciate ligament
Tear at the posterior horn of the medial meniscus
Lateral dislocation of the proximal tibia
Primary bilateral gonarthrosis (osteoarthritis of the knee)
Patella dislocation
Diagnosis
Sprain of the anterior cruciate ligament
Habitual subluxation of the patella
Acute meniscal tear
Tear of the anterior cruciate ligament
Meniscal ganglion
Chronic instability of the knee joint
Meniscus damage from old tear or old injury

Diagnosis


Injury type
Other
Meniscus
Cruciate Ligament
Urgency
Minor
Major
Other Minor
Meniscus Minor
Meniscus Major
Cruciate Ligament Minor
Cruciate Ligament Major

Diagnosis


1657
Meniscus Minor
354
Cruciate Ligament Minor
Other Minor
9633
Meniscus Major
9185
Cruciate Ligament Major
2377

Data fields

Anamnesis

- Patients' symptoms from their perspective
- Patient history
- Informal language

Sudden shooting pain when standing up from a squat. Two years ago, a popping sensation in the knee when straightening the joint, followed by a period without symptoms. (…)

Diagnosis

- ICD Code
- Doctor description

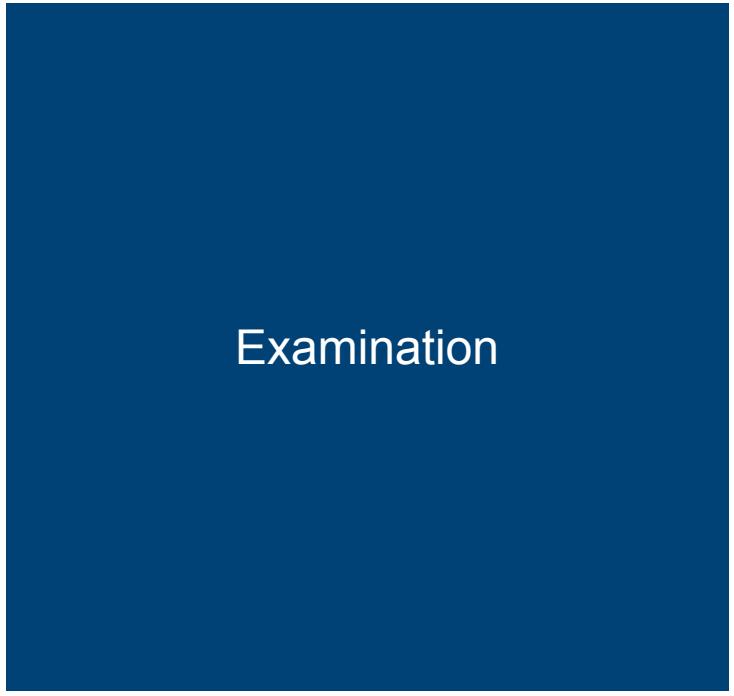
M23.3 Acute meniscal tear

Examination

- Medical jargon
- Visual observations
- Results of orthopedic tests

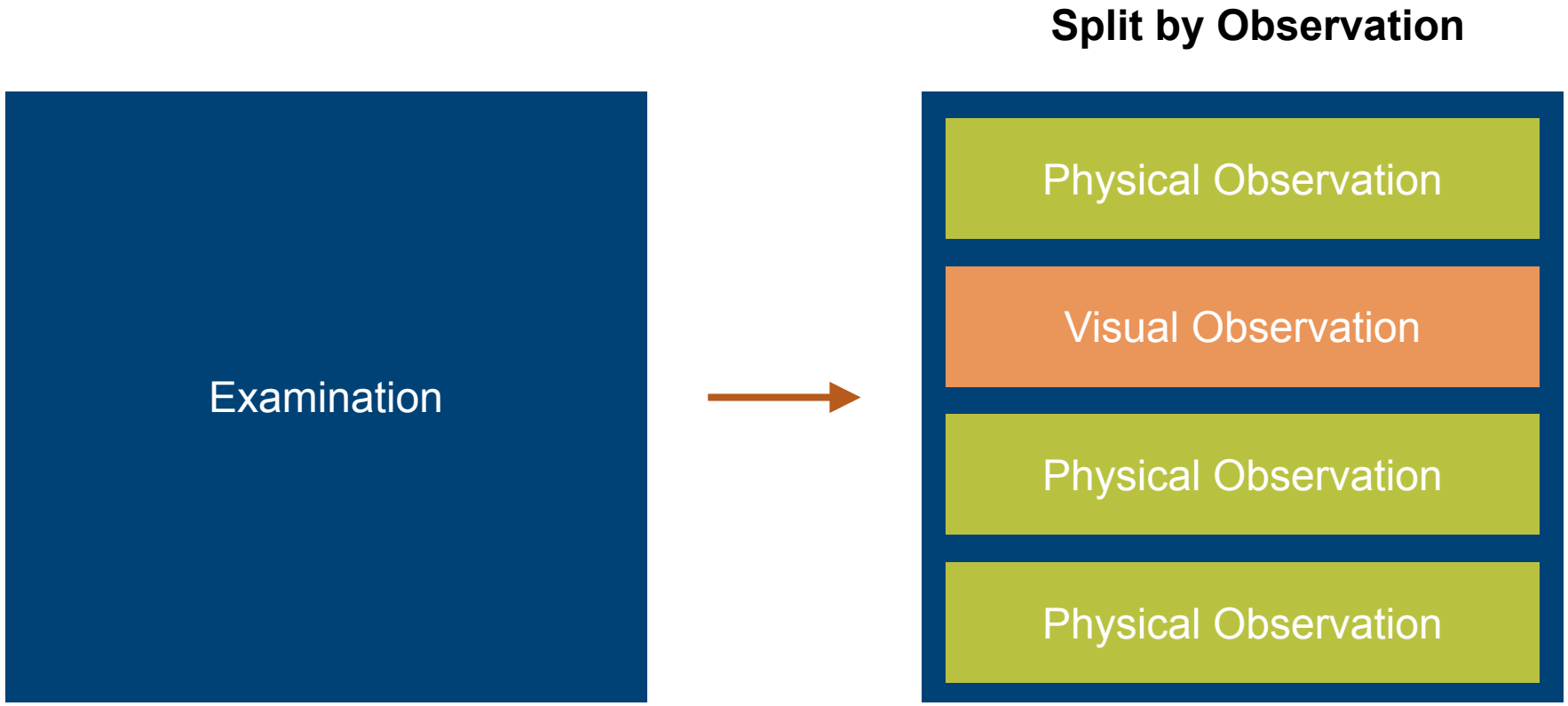
(…) Lachman test negative and firm, PP in JS, Steinmann test positive,Pivot-Shift test negative (…)

Examination Interpretation

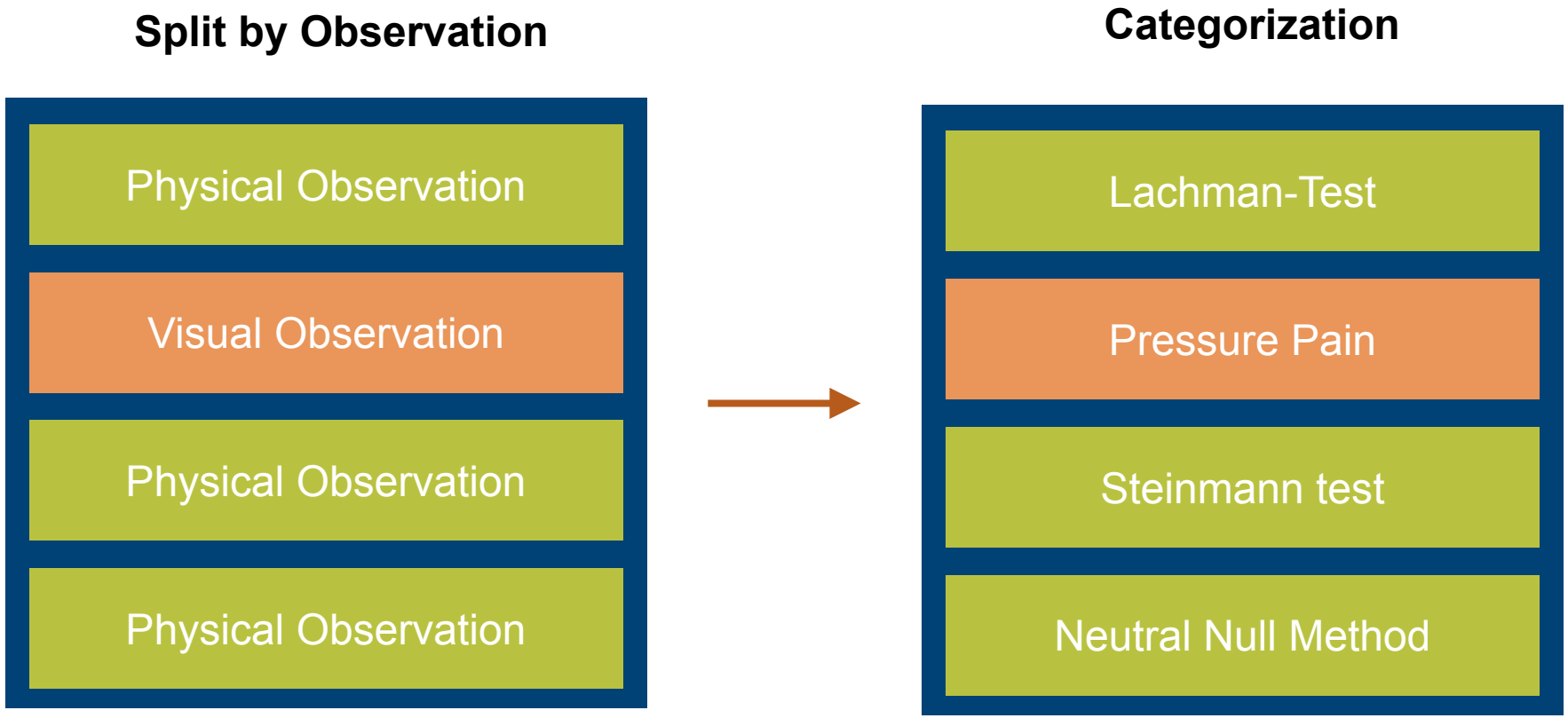


- No similarity to patient inputs
- Difficult to interpret the results
- Observations a patient can not do on their own

Examination Interpretation

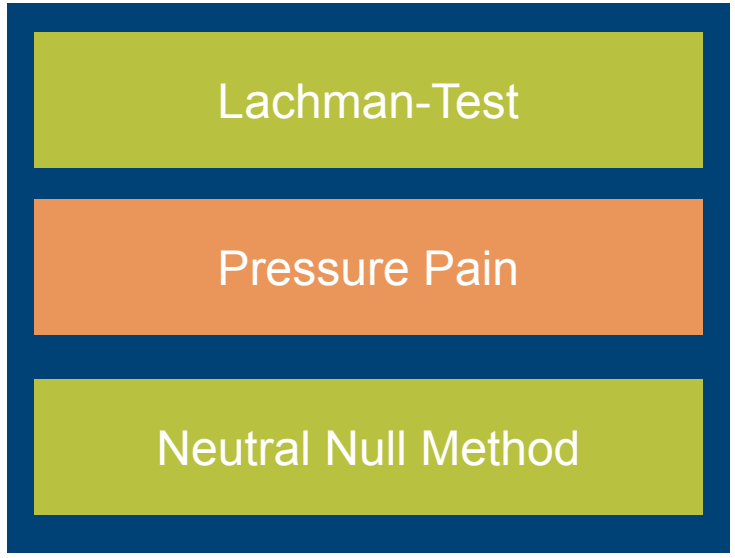


Examination Interpretation

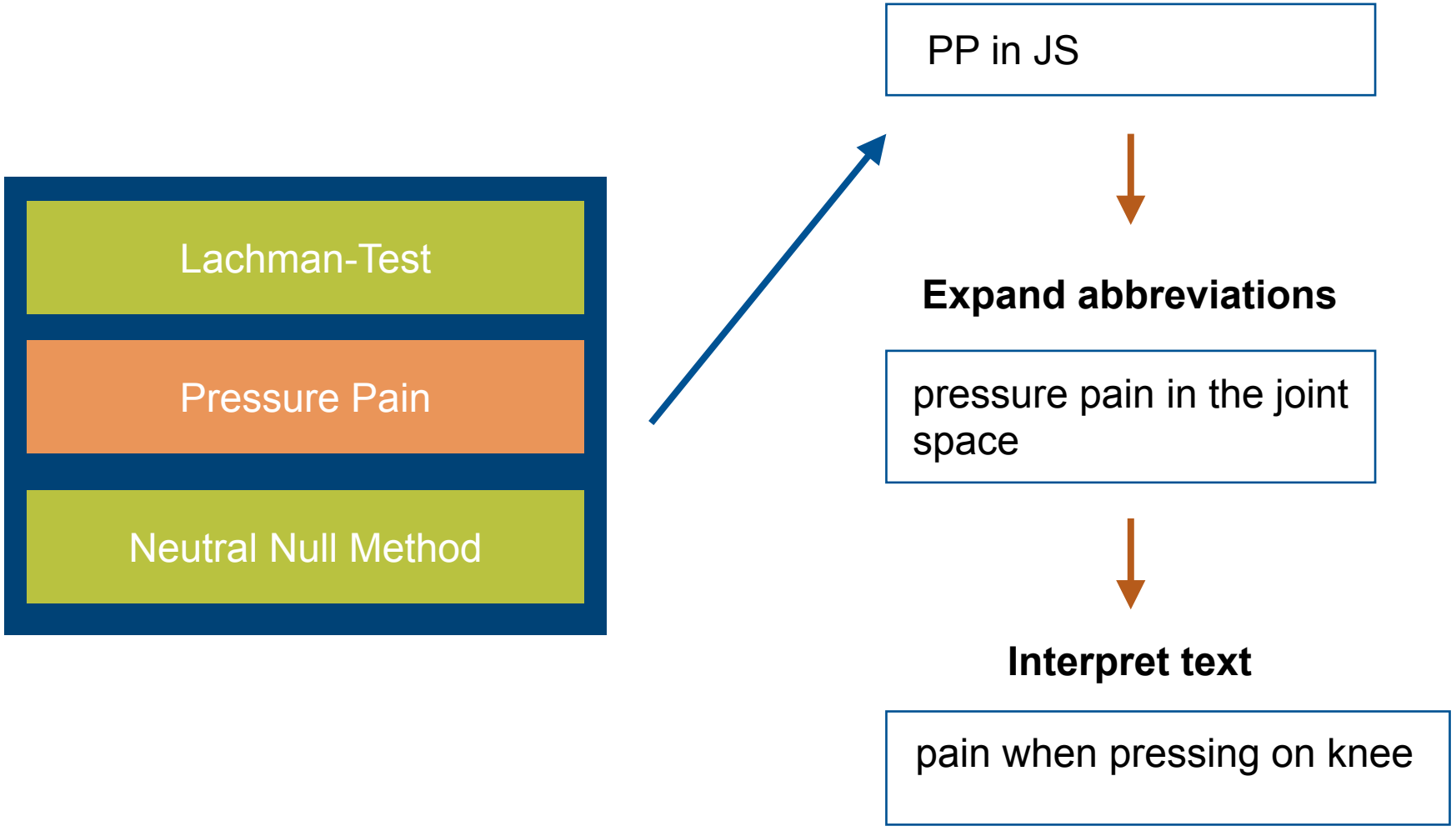


Examination Interpretation

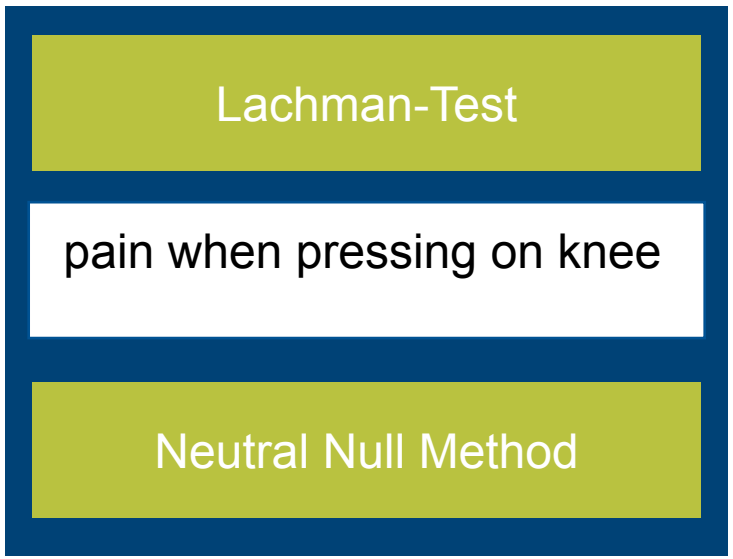
Filtering



Examination Interpretation

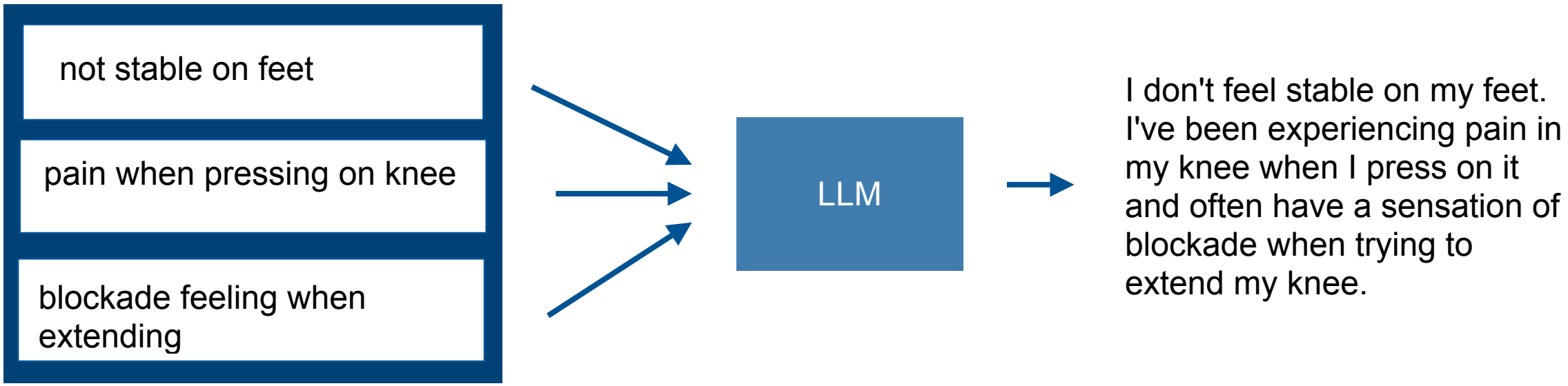


Examination Interpretation



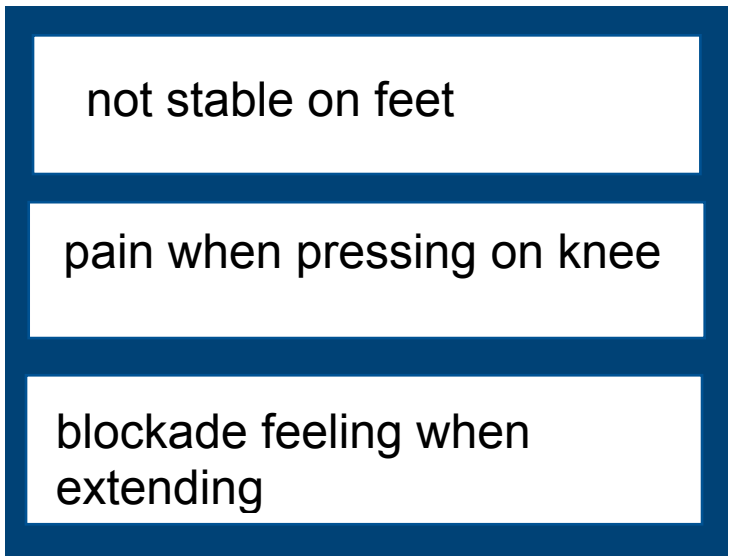
Examination Interpretation

Interpreted observations



Examination Interpretation

Interpreted observations



LLM

Interpreted examination

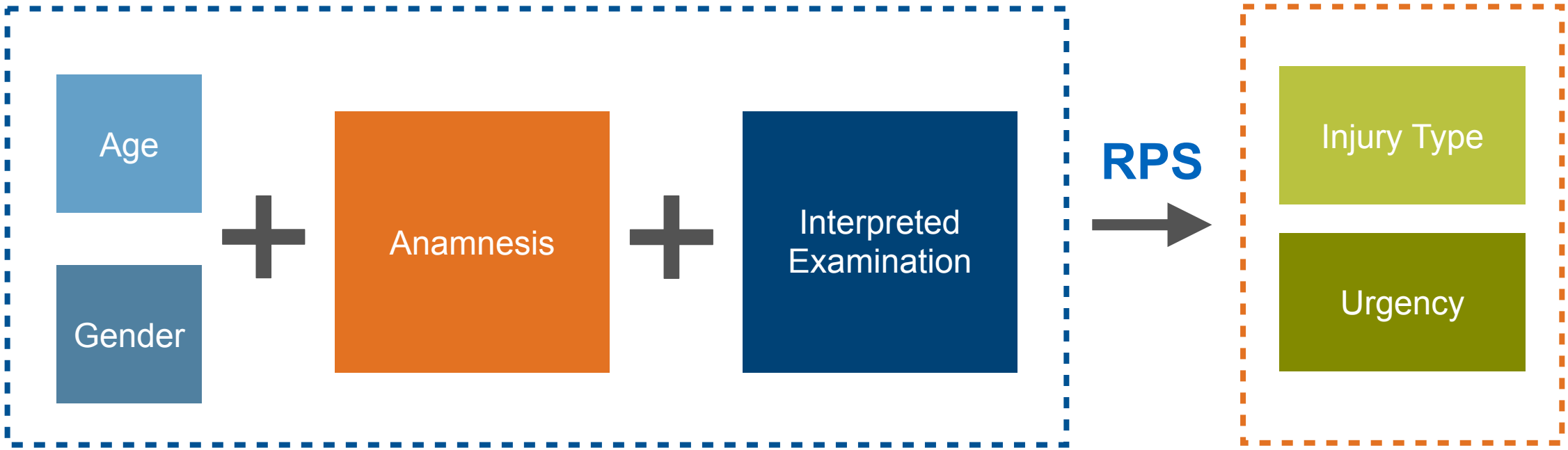
I don't feel stable on my feet. I've been experiencing pain in my knee when I press on it and often have a sensation of blockade when trying to extend my knee.

vs.

Original examination

(…) Lachman test negative and firm, PP in JS, Steinmann test positive,Pivot-Shift test negative (…)

Final Data Preparation



Keyword extraction

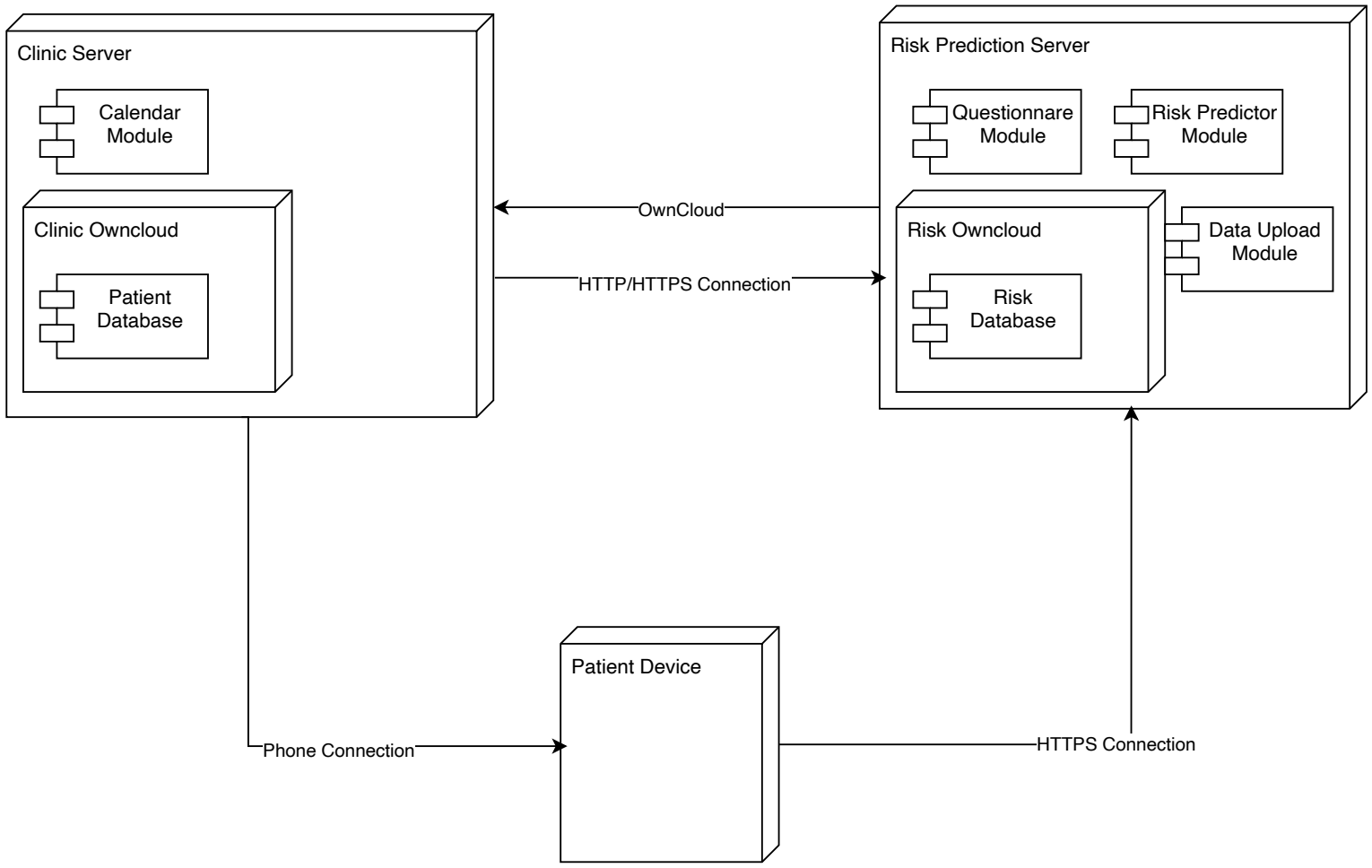
- Hypothesis: Free text → Information structures → Better performance
- RAKE* algorithm - extracting keywords while preserving context

I am **60 years old**. I **don't feel stable** on my feet. I've been experiencing **pain in my knee** when I **press** on it and often have a sensation of **blockade** when trying to **extend my knee**, but I **don’t have any extension deficit**.

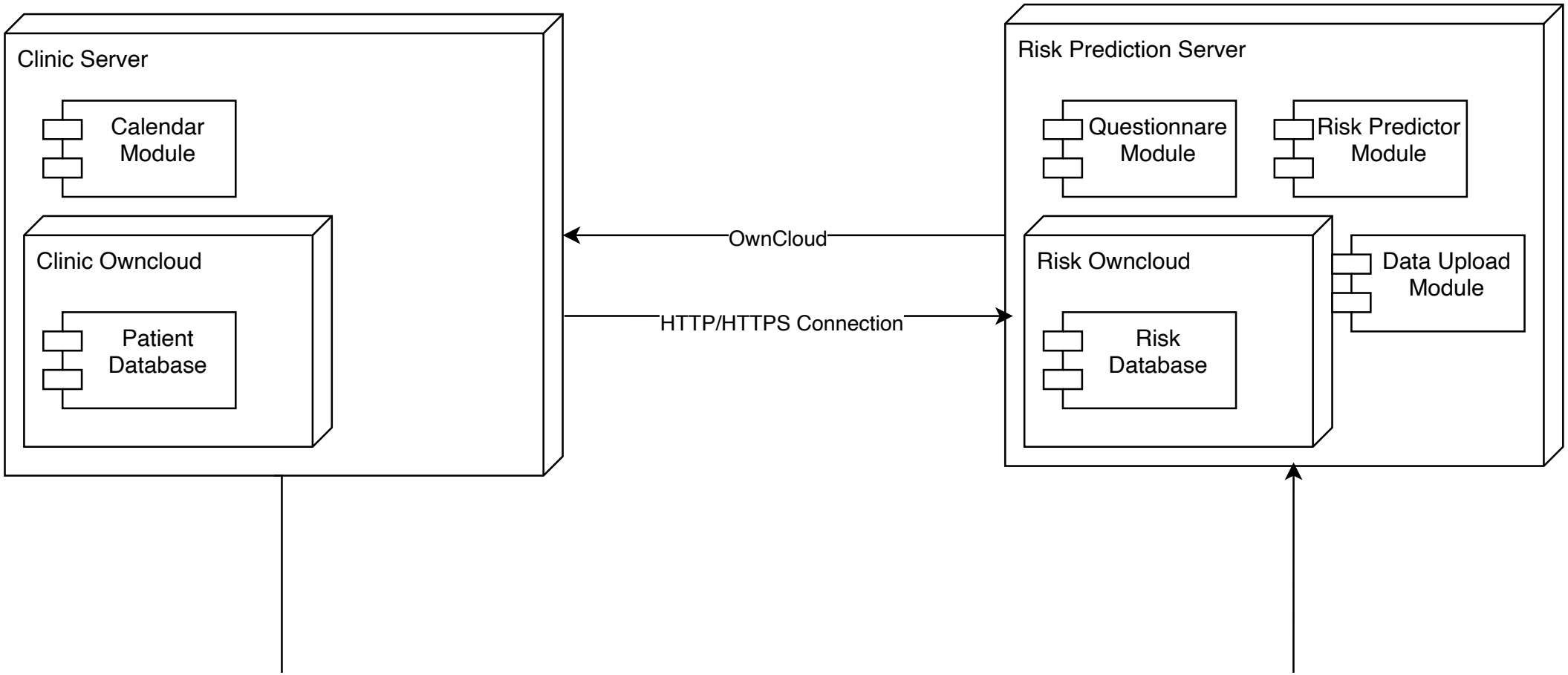
Keyword extraction using RAKE on an example patient anamnesis

* Stands for Rapid Automatic Keyword Extraction

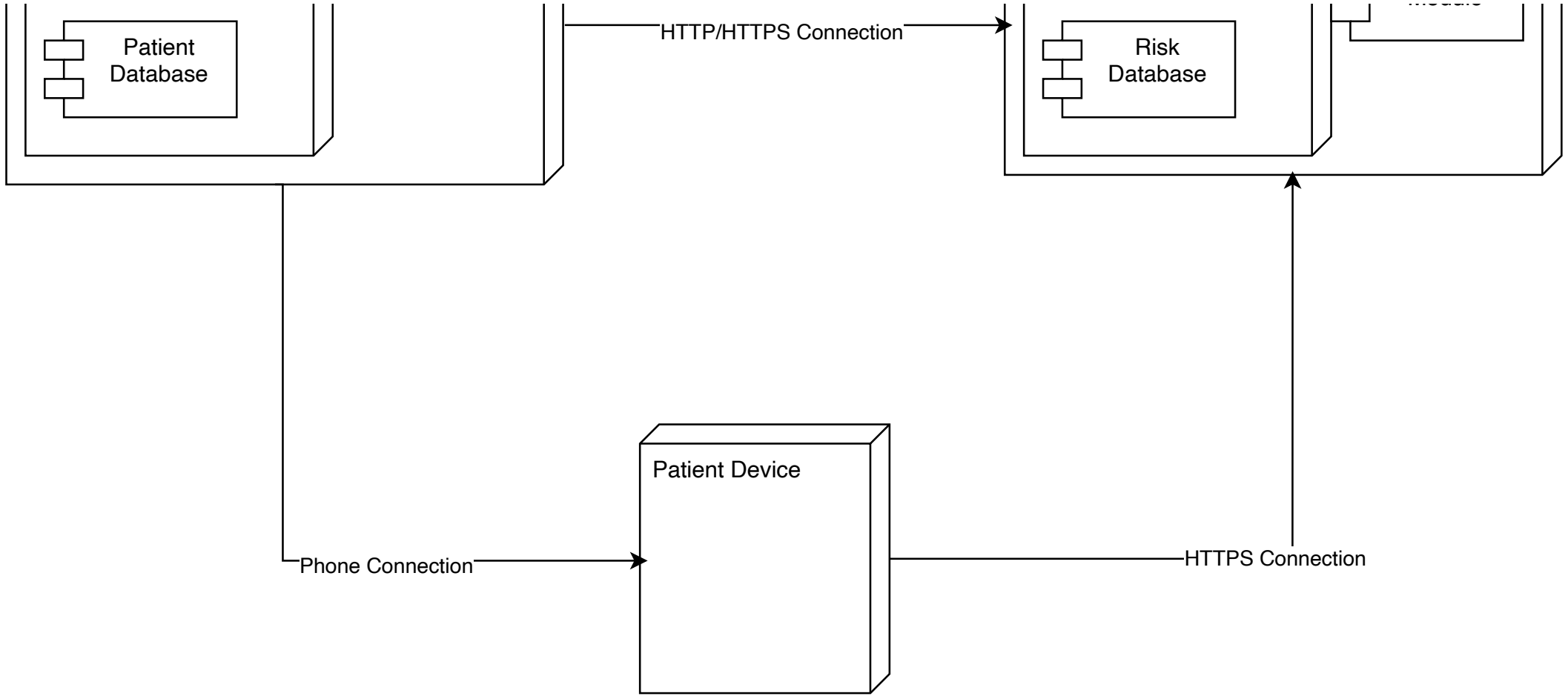
RPS Subsystem Decomposition



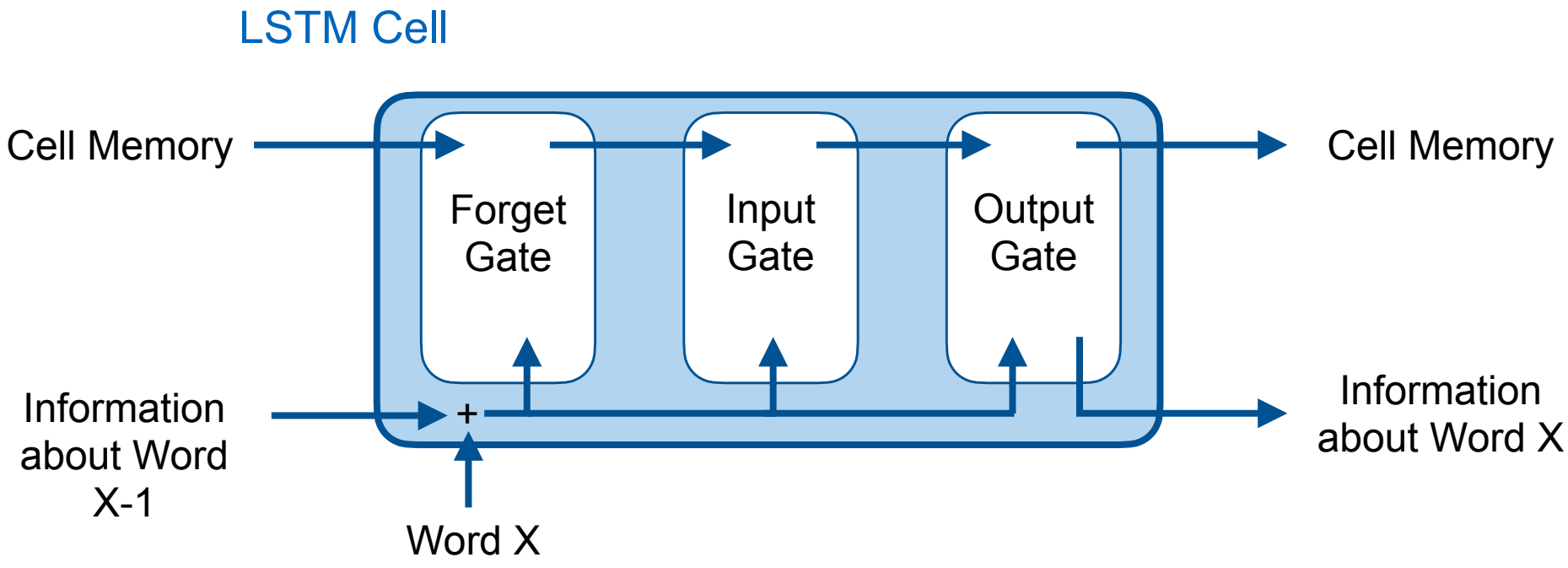
RPS Subsystem Decomposition



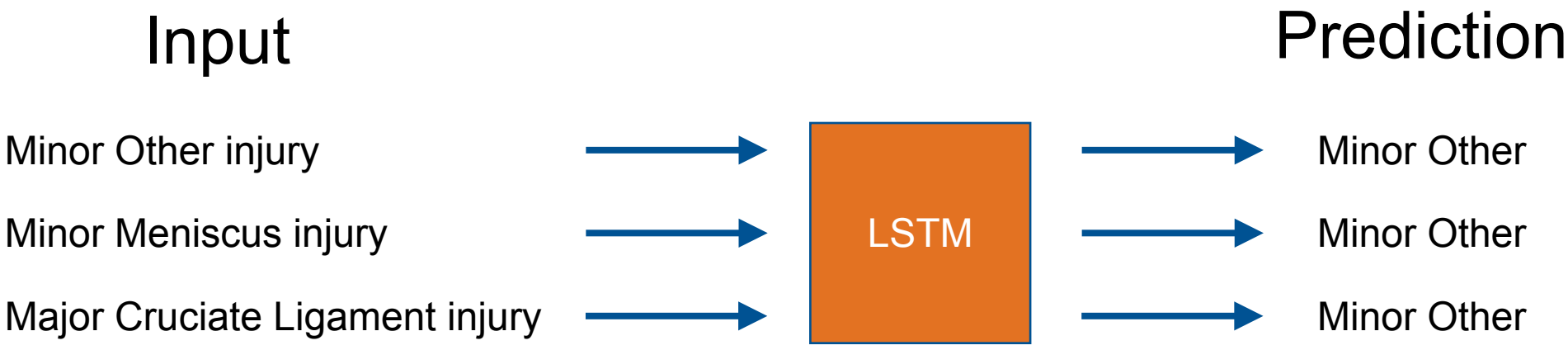
RPS Subsystem Decomposition



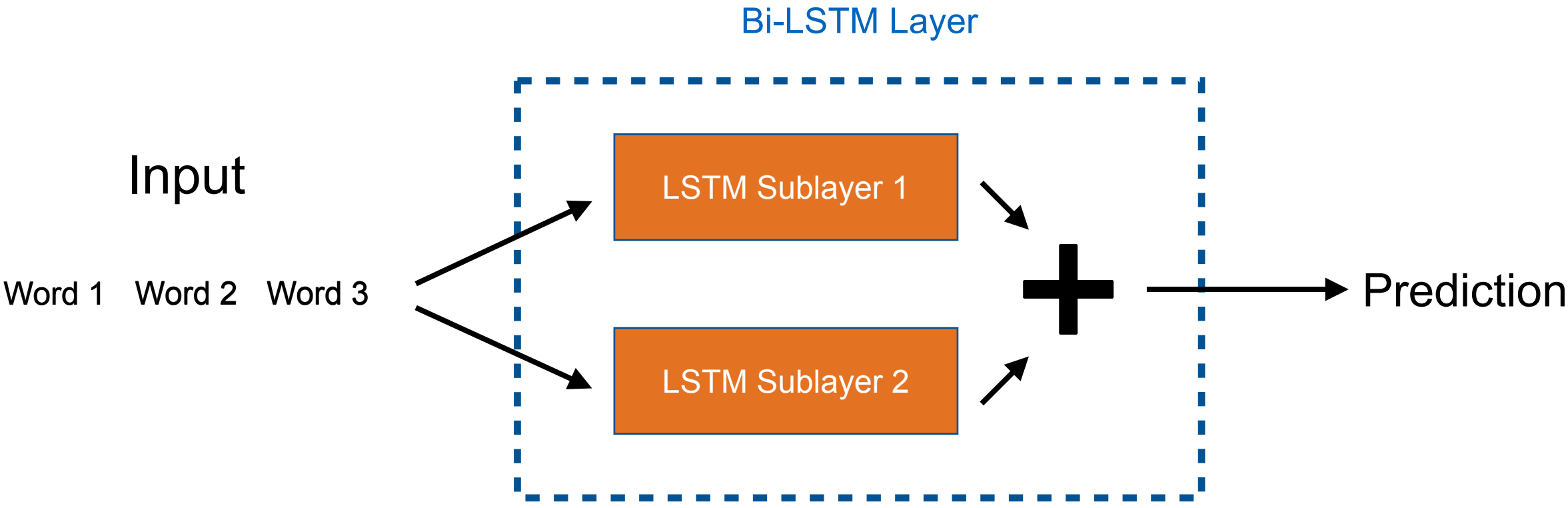
LSTM Cell


LSTM Cell
Cell Memory
Forget Gate
Input Gate
Output Gate
Cell Memory
Information about Word X-1
+
Information about Word X
Word X

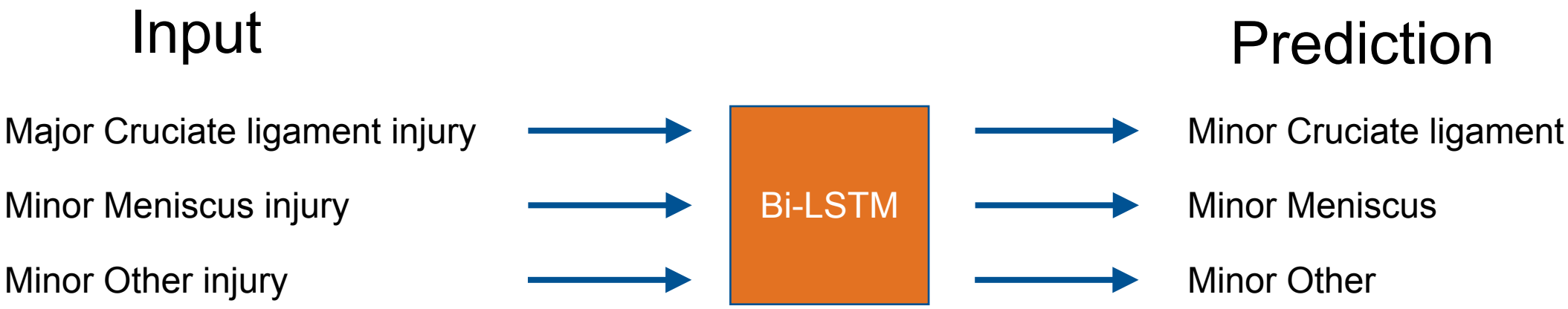
LSTM Baseline



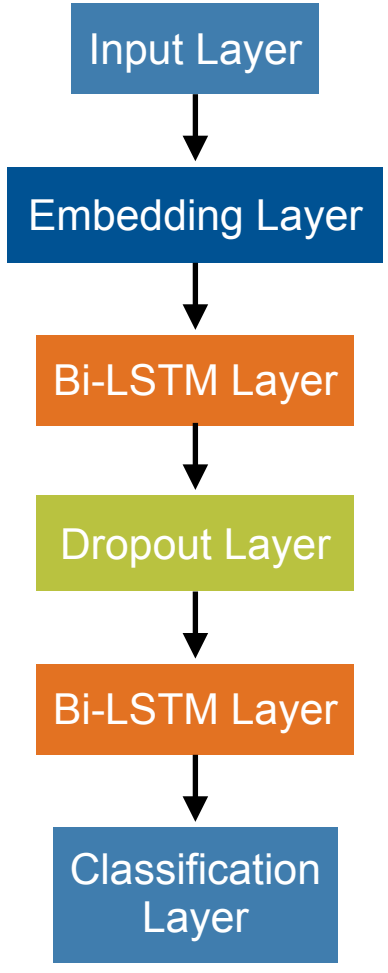
LSTM Baseline



LSTM Baseline



LSTM Baseline



Takes the hospital information

Transforms this information to a machine readable format

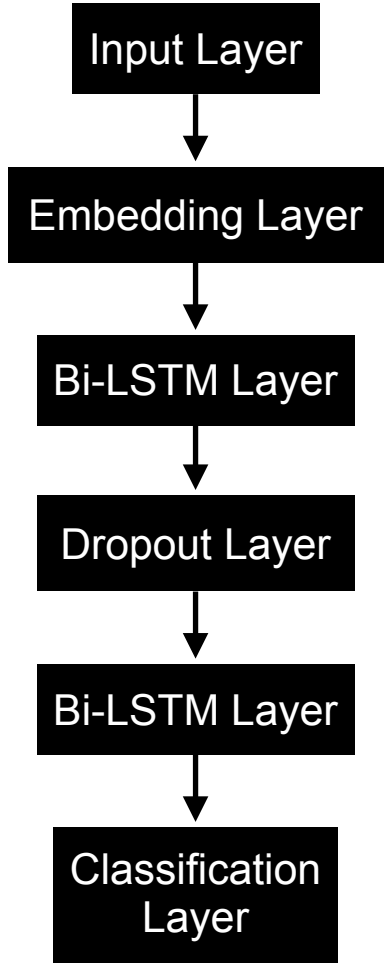
LSTM Layer which looks at the data in both directions

Deletes half of the data

Takes the output of the Bi-LSTM layer and maps it to a prediction

LSTM Baseline

- Evaluations used accuracy, macro F1 score
- Baseline achieved:
  - 67% accuracy
  - 58% macro F1 score



LSTM Optimizations

Sampling Techniques

Batch Normalization

Attention Layer

Layer Amount

Convolutional Layer

Class Weights

Dense Layer

Embeddings

Regularization Techniques

LSTM Optimizations

Attention Layer

Layer Amount

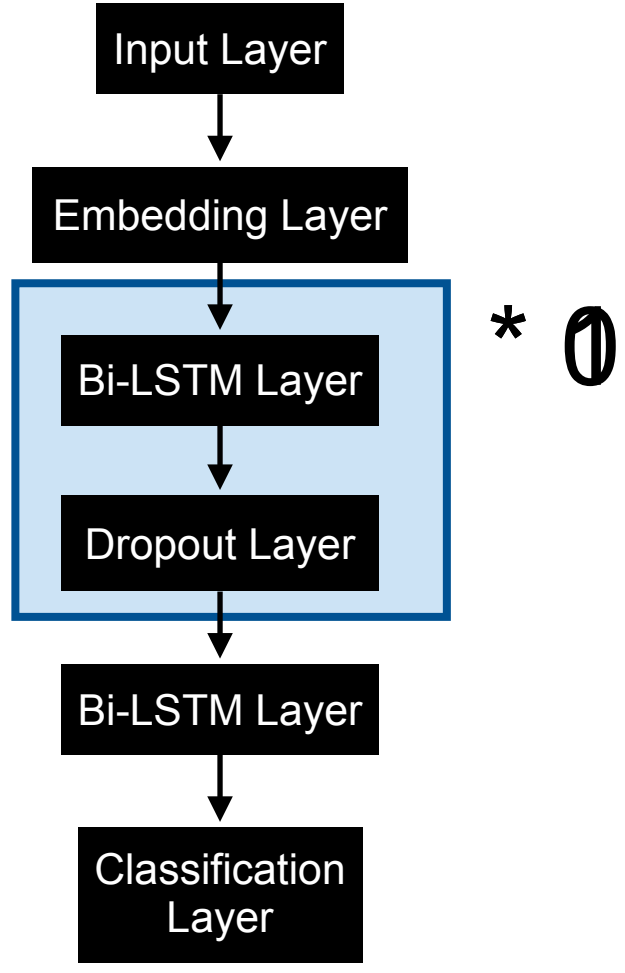
Convolutional Layer

Dense Layer

Layer Amount

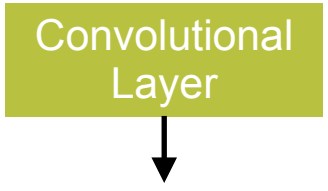
- Fewer layers may generalize better, avoiding overfitting, especially in simpler tasks

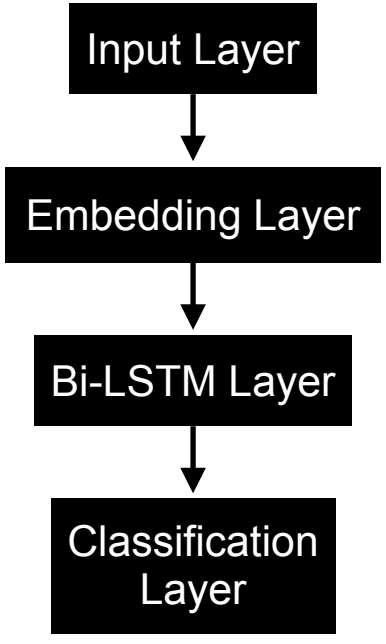
Baseline



Convolutional Layer

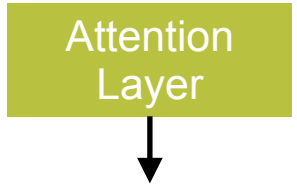
- Focus on important parts of the input

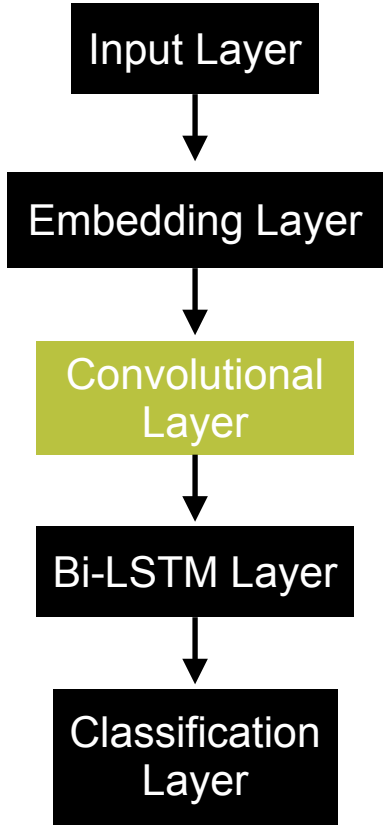




Attention Layer

- Tells classification layer which parts are the most important

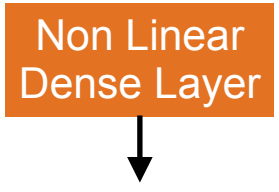


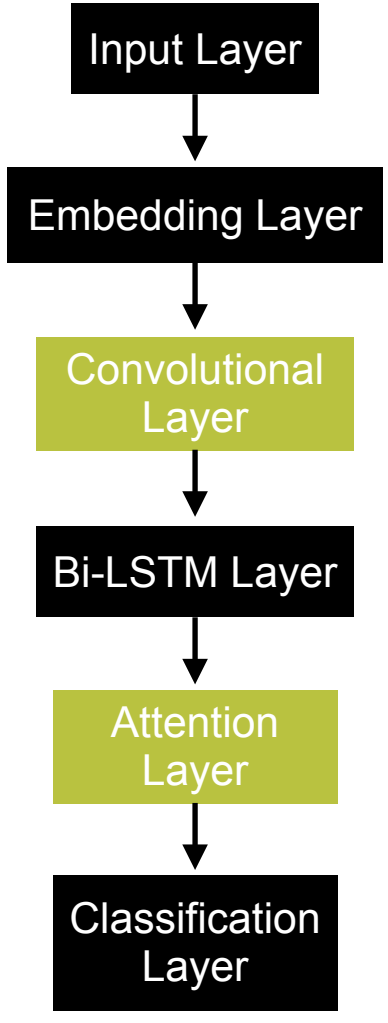


Final Model

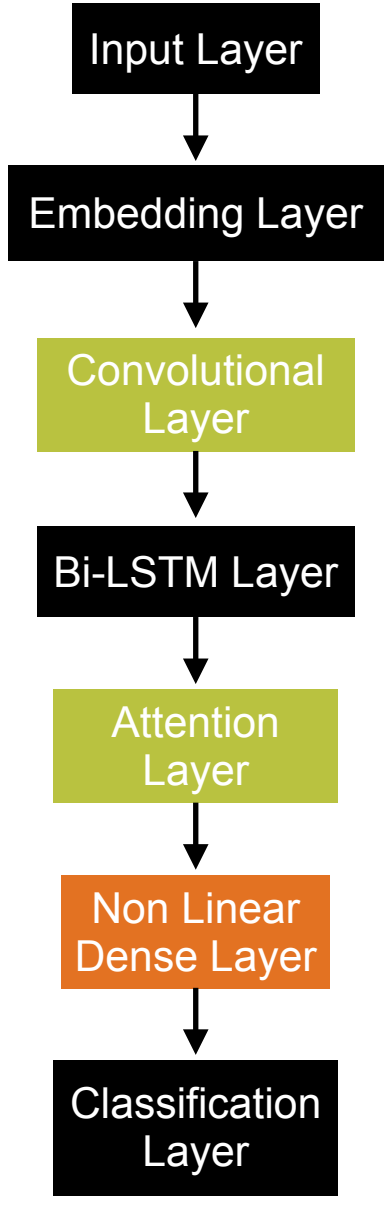
Dense Layer

- Adds variety to the model





Final Model

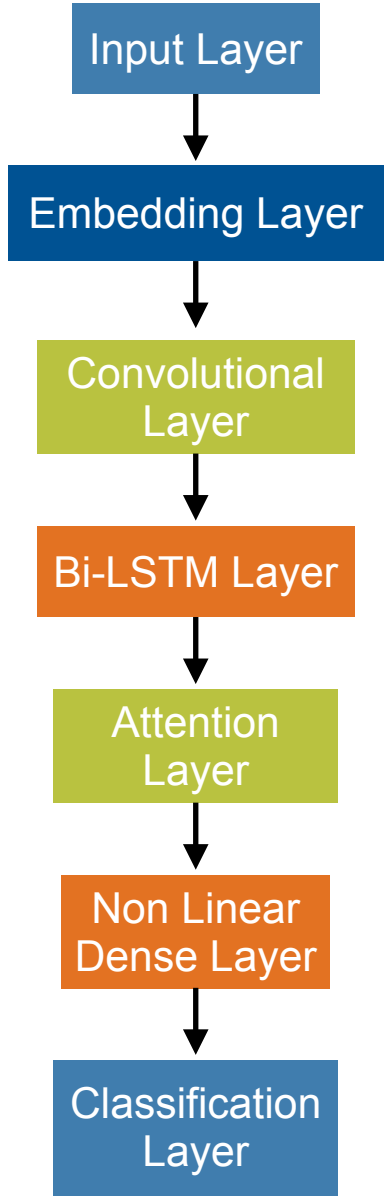

Input Layer
Embedding Layer
Convolutional Layer
Bi-LSTM Layer
Attention Layer
Non Linear Dense Layer
Classification Layer

Final Model

- Incorporates four optimizations
- Not all experiments with positive results, worked together with other optimizations

78% Accuracy + 16%

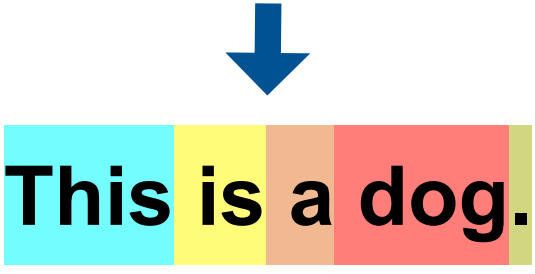
74% macro F1 score + 27%



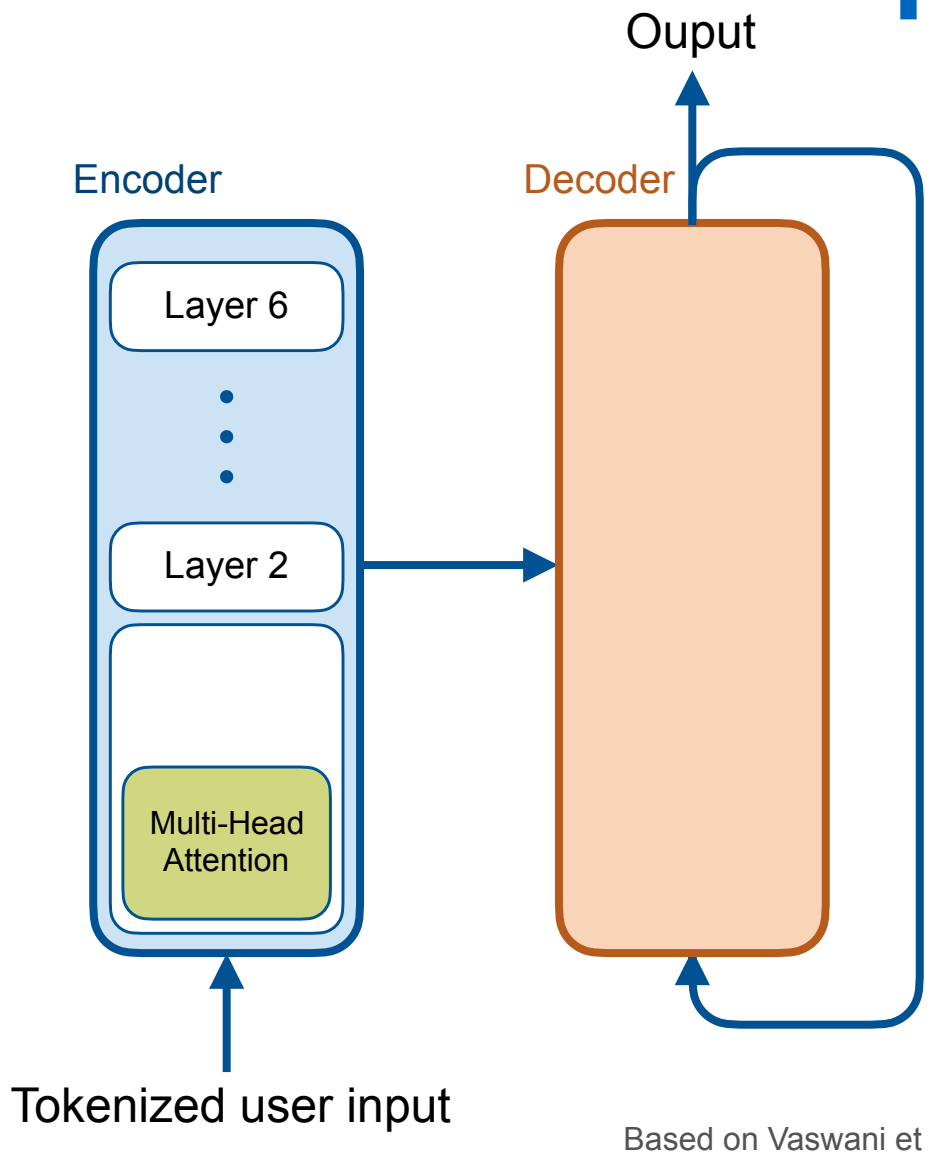
Transformer Structure

- Tokenizer - splitting sequences into smaller information structures (tokens)

This is a dog.



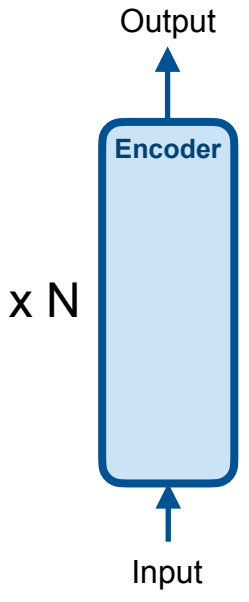
- Transformers - predecessor of LLMs
  - Encoder (text understanding) and Decoder (text generating) with 6 layers each
  - Multi-Head Attention sublayer - captures relationship between words



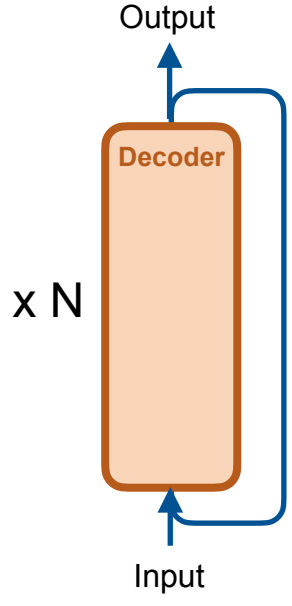
Based on Vaswani et al., 2017

LLM Definition and Structure Types

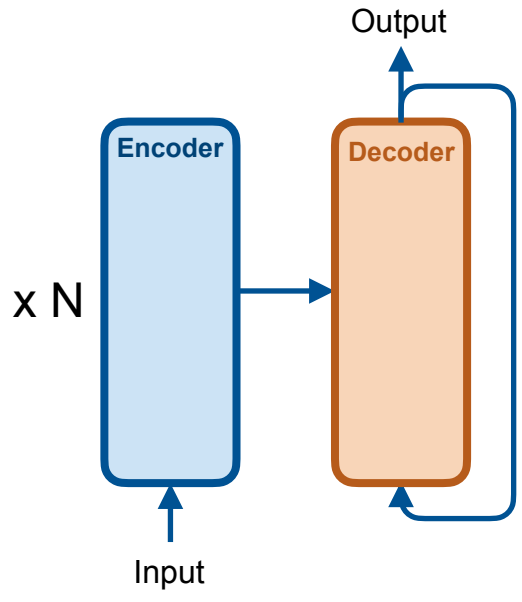
- LLM (Large Language Model) - Transformer-based model pre-trained on big amounts of data
- LLM Types - Encoder, Decoder and Encoder-Decoder LLMs



a) Encoder LLMs



b) Decoder LLMs

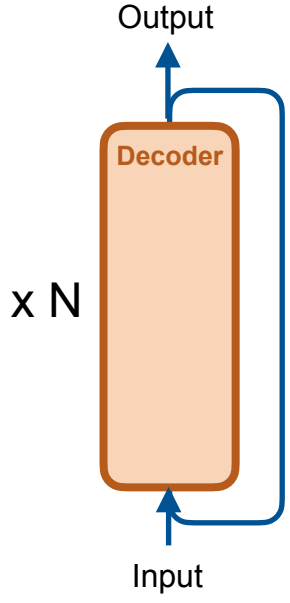


c) Encoder-Decoder LLMs

LLM Definition and Structure Types

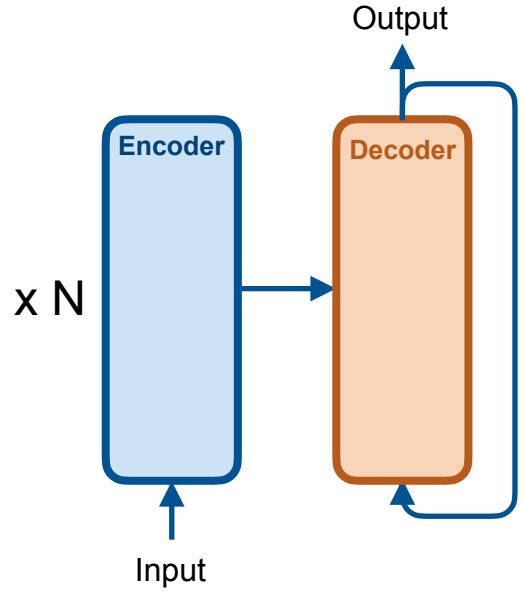
a) Encoder LLMs

- Best for understanding, e.g. classification
- BERT, RoBERTa



b) Decoder LLMs

- Best for text generating
- GPT, Llama



c) Encoder-Decoder LLMs

- Best for generating text based on whole input, e.g. translation
- T5

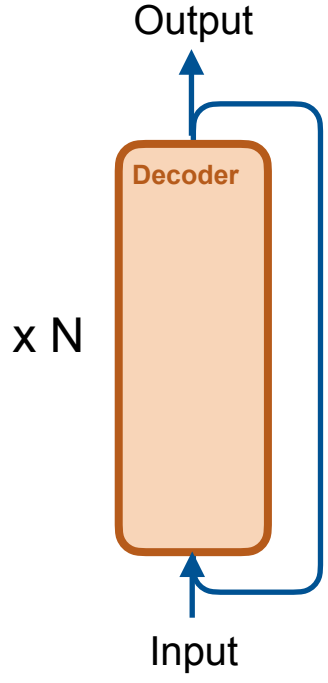
LLM Structure Selection - Llama vs. BERT

Dataset diagnosis

Other meniscus damage: other and unspecified part of the medial meniscus

Llama diagnosis

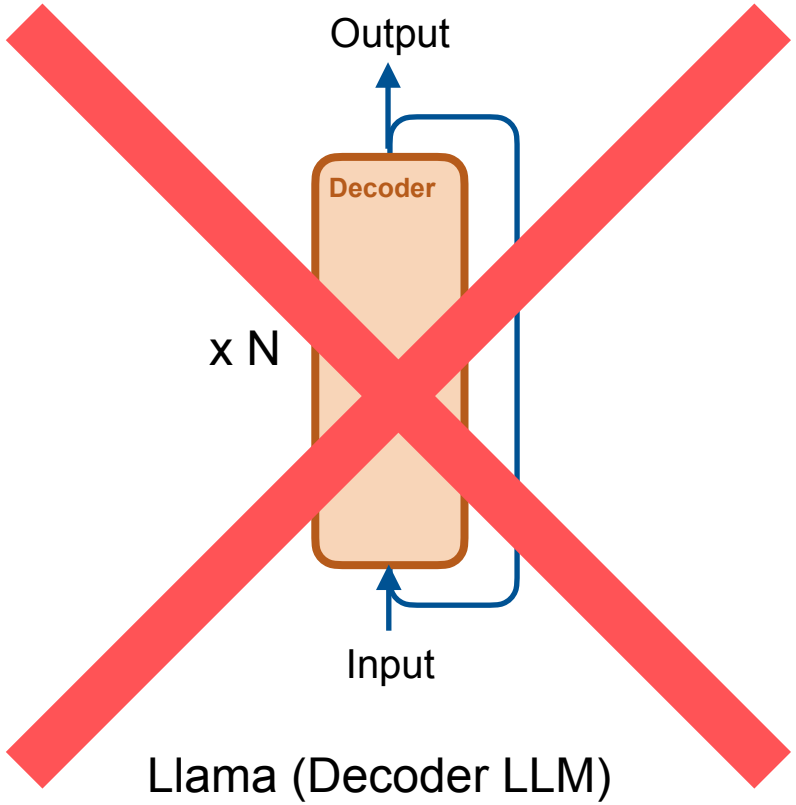
Acute meniscal tear



Llama (Decoder LLM)

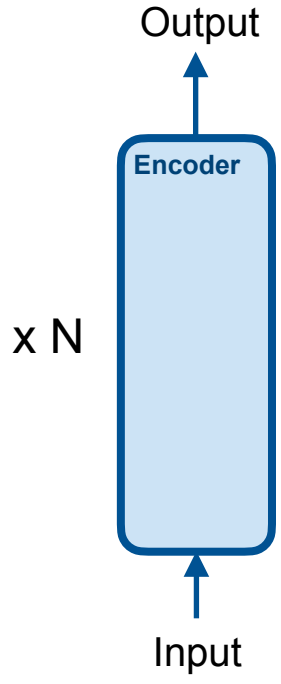
→ Complex validation of results

LLM Structure Selection



Llama (Decoder LLM)

→ Complex validation of results



BERT (Encoder LLM)

- Excels at classification
- Understands input well

BERT Background

- **BERT** (Bidirectional Encoder Representations from Transformers)
- 12 layers (Devlin et al., 2018) - twice as many as Transformers
- Bidirectional Attention - understands token context on both sides

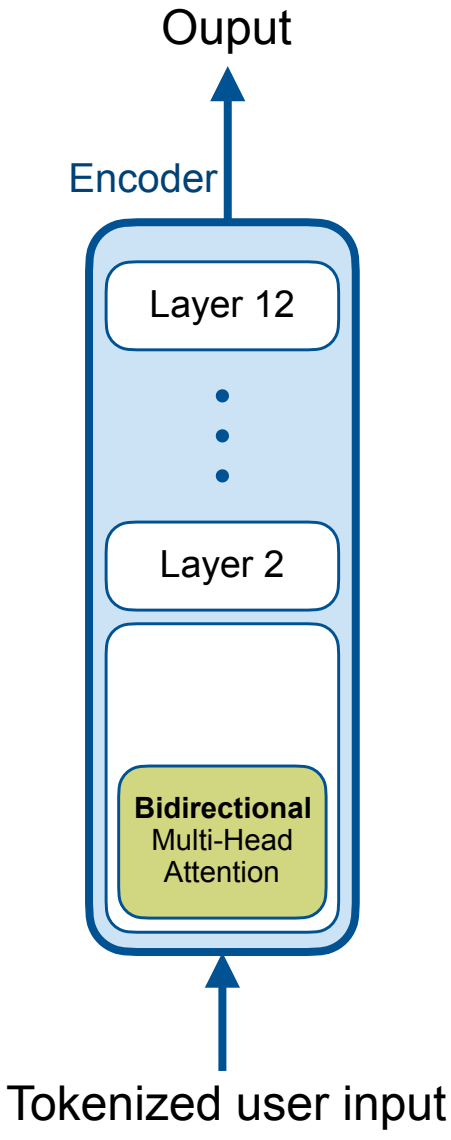
Unidirectional **There is a dog playing outside.**

Bidirectional **There is a dog playing outside.**

- Trained using a Masked Language Model - “fill the blank with **1** token”

A **[MASK]** is a mammal with sharp teeth, an excellent sense of smell, and a fine sense of hearing.

BERT: 96 %, dog



BERT Baseline

Only predicts 1 token at a time

Sudden shooting pain when standing up from a squat. Two years ago, a popping sensation in the knee when straightening the joint (…). The diagnosis with urgency is: **[MASK]**

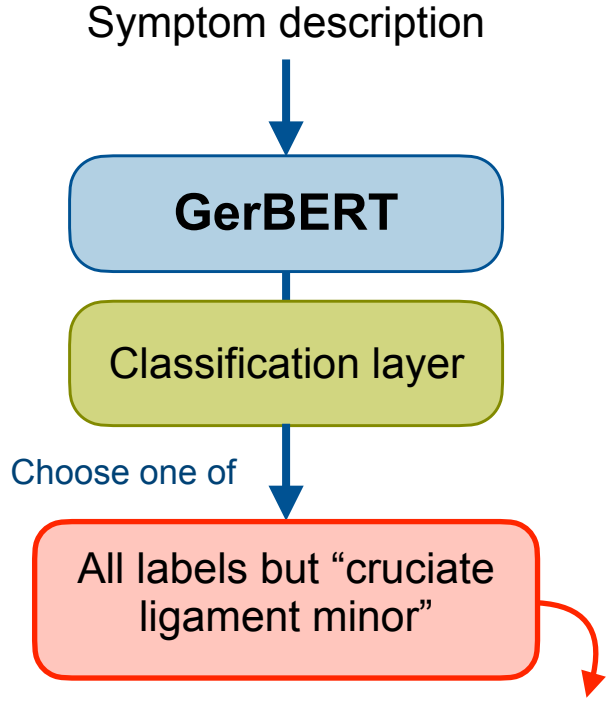
✗ **BERT:** 56 %, bad

✓ **BERT:** Meniscus urgent

→ Classification layer with default parameters

German understanding

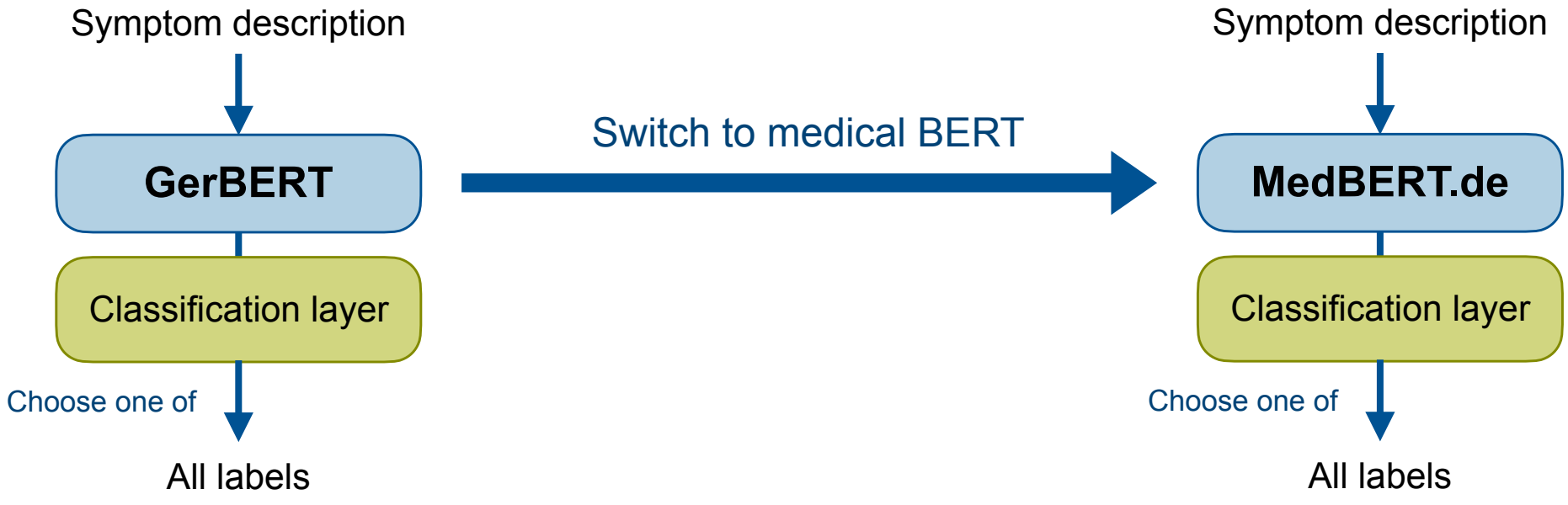
→ German BERT



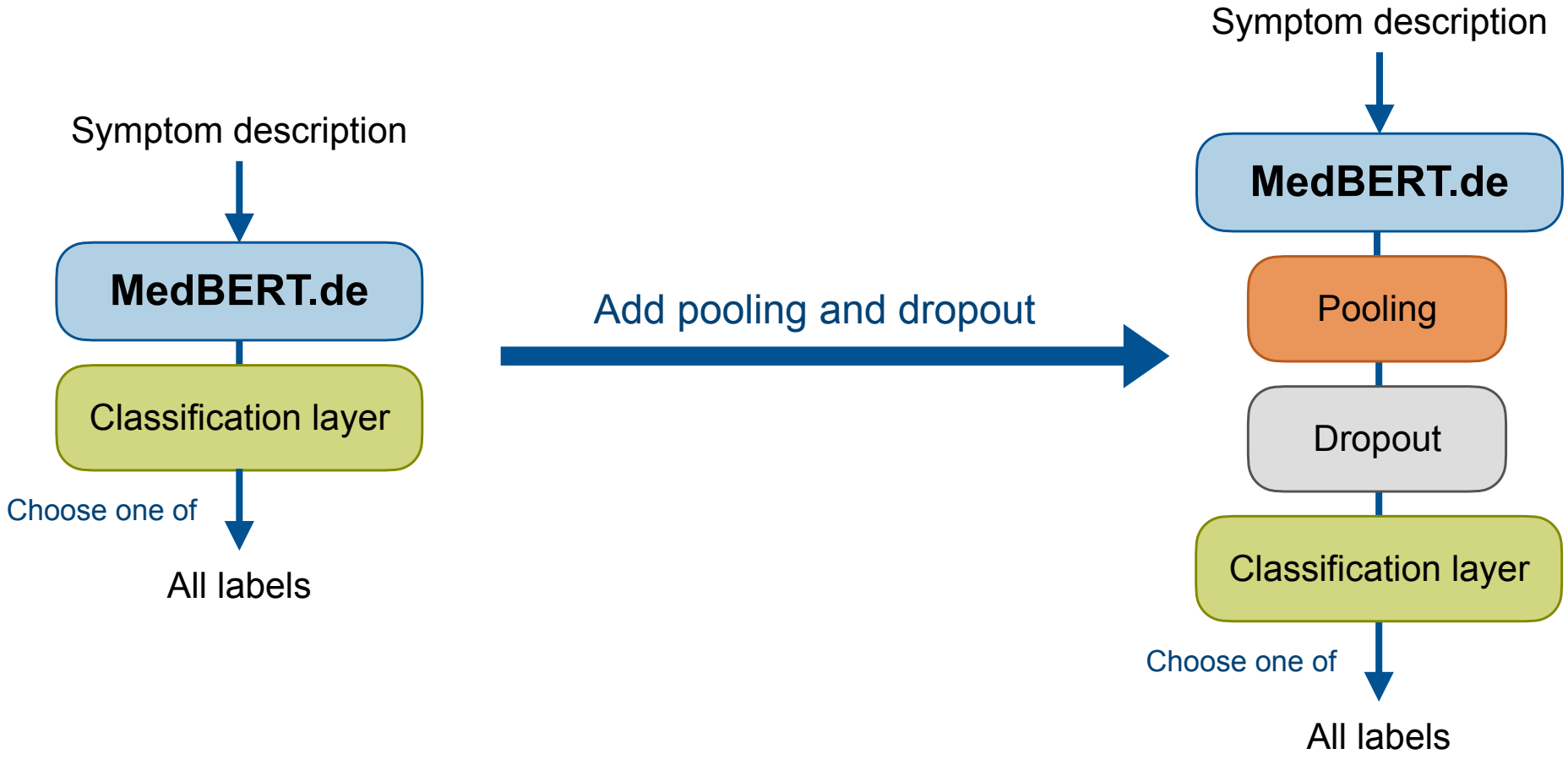
56% Accuracy, **35%** F1 macro score

Oversampling

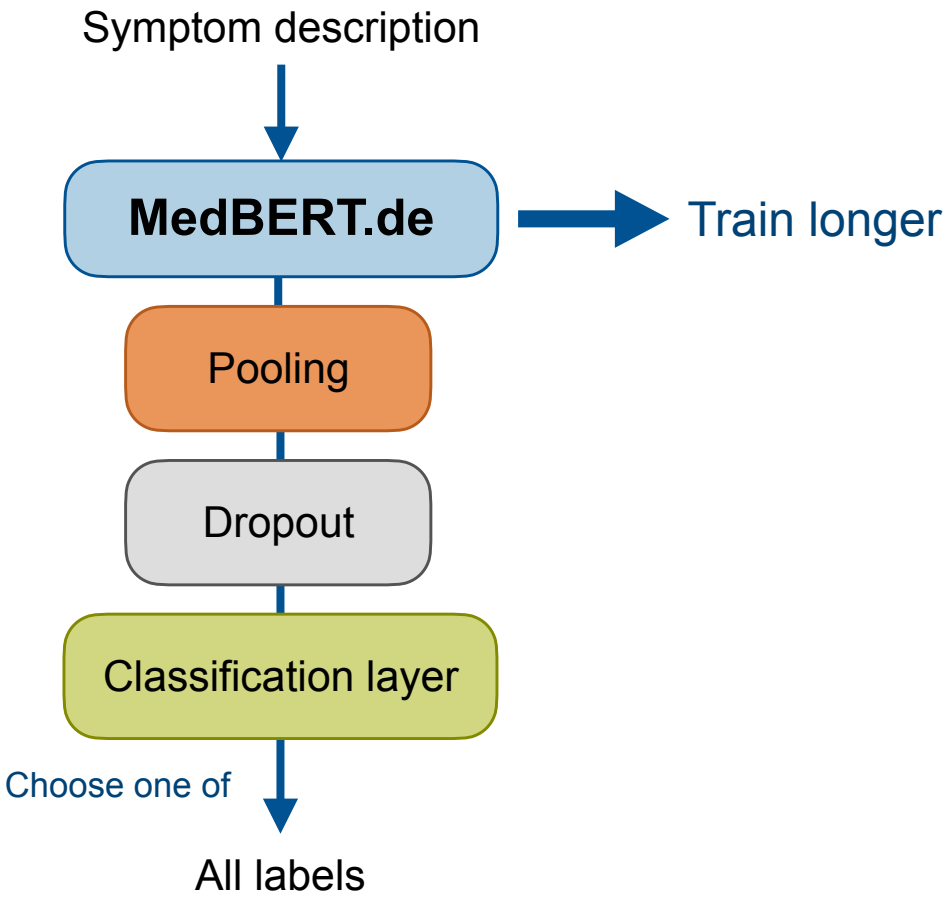
Fine-tune for medical knowledge



Structural Extension



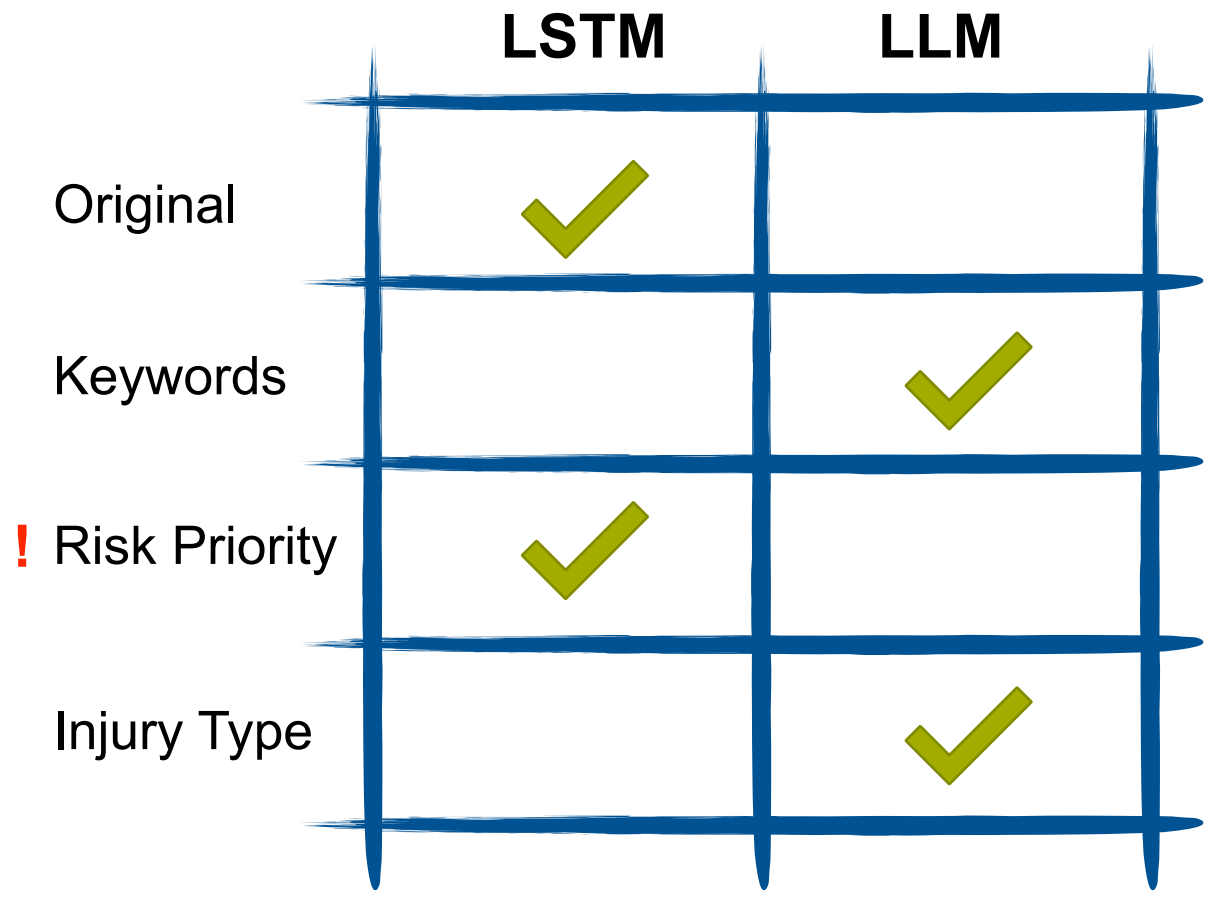
Final model



74% Accuracy + 14%

70% F1 macro score + 35%

Evaluation



- Noise vs. Information loss
- Over vs. underprioritization
- Meniscus vs. Cruciate ligament vs. Other

→ LSTM Final Risk Predictor

Conclusion

Summary

- 40.000 data points from Sportsclinic Cologne
- Accuracy of 78%
- LSTM as final choice, but almost identical results
- Plenty of future possibilities

Contributions

- Comparison of two AI approaches
- Proof-of-concept RPS via web-portal
- Data processing to transform examinations to fluent informal text
- iPad App for data collection

Thank you for the attention!

Any questions?