Augmenting Pathologists with NaviPath: Design and Evaluation of a Human-AI Collaborative Navigation System

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Background

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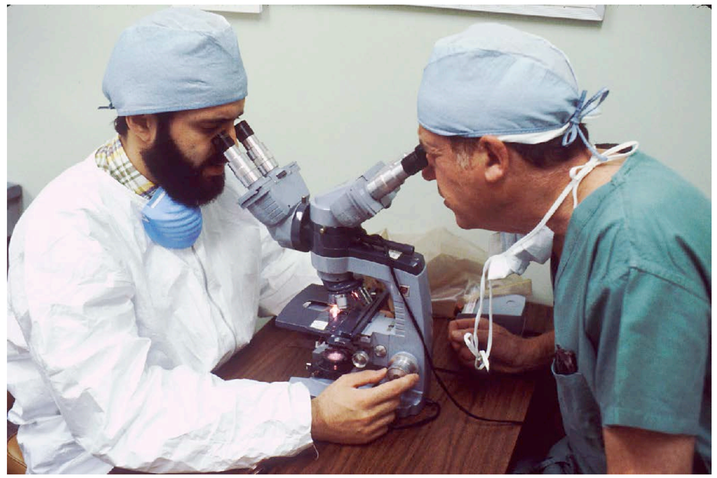
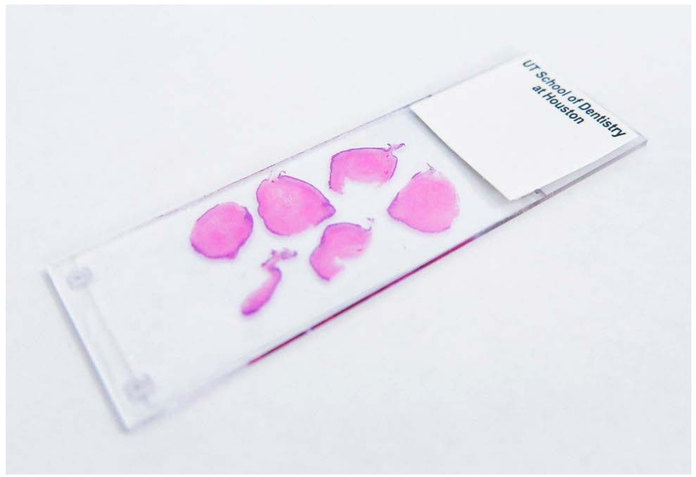
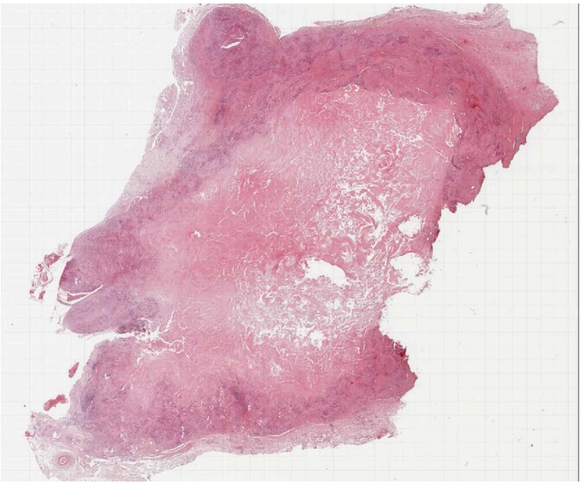
Background

Pathology & Navigation







1. *Middle image credit: National Cancer Institute*
2. *Middle image credit: https://dentistry.uth.edu/about/news-media/story.htm?id=41ee048e-a7d7-48f7-a1df-ba1e1f833e25*
3. *Locating mitoses in digital pathology scans*

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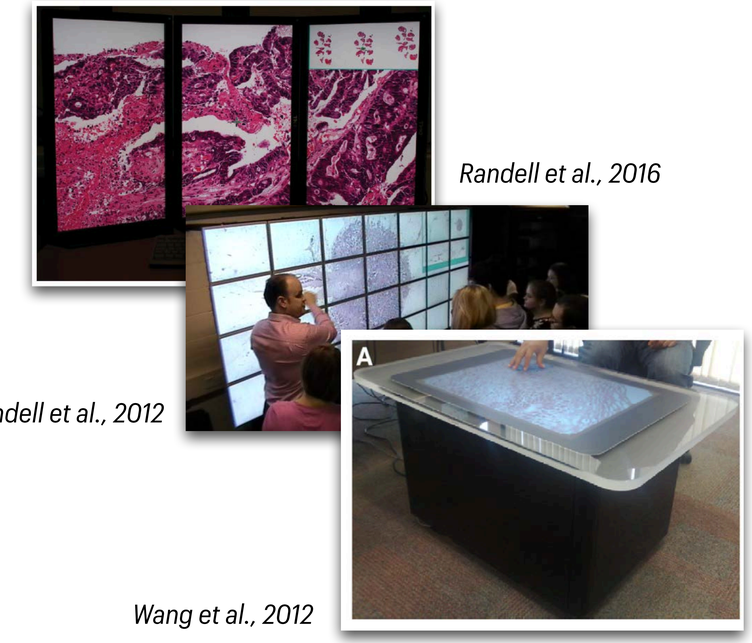
Background

Related Work

Solution #1: Hardware

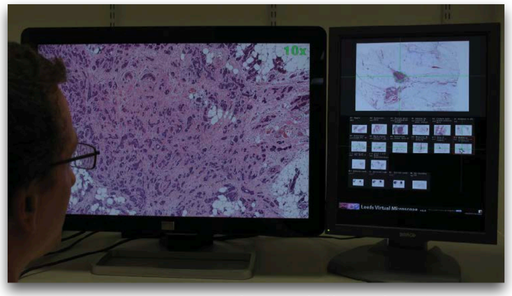


Randell et al., 2016

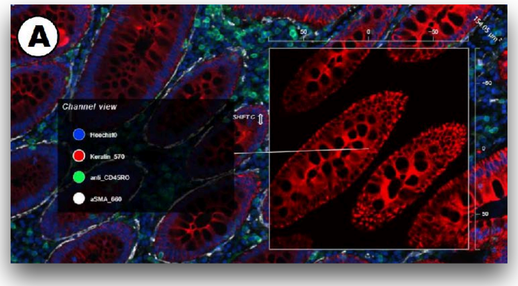
Randell et al., 2012

Wang et al., 2012

Solution #2: Interface Deigns

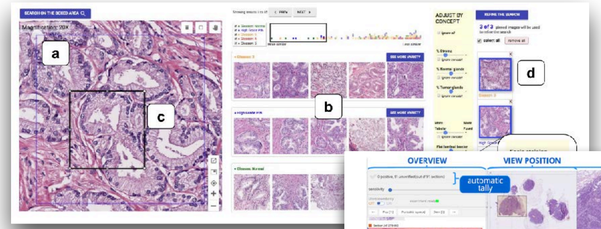


Overview + Detail. Randell et al., 2016

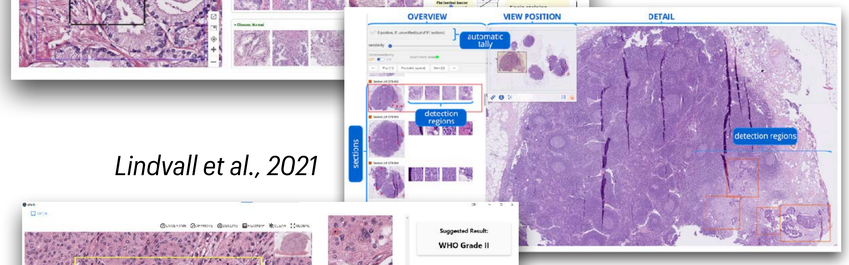


Focus + Context. Jessup et al., 2021

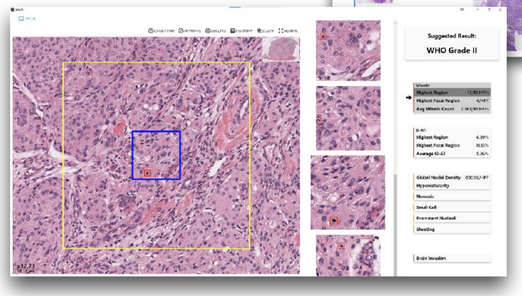
Solution #3: Human-AI Collaboration



Cai et al., 2019



Lindvall et al., 2021



Gu et al., 2022

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Background

Motivation

A human-AI collaborative system that enhances pathologists' navigation by incorporating pathologists' domain knowledge and considering their workflow integration in practice.

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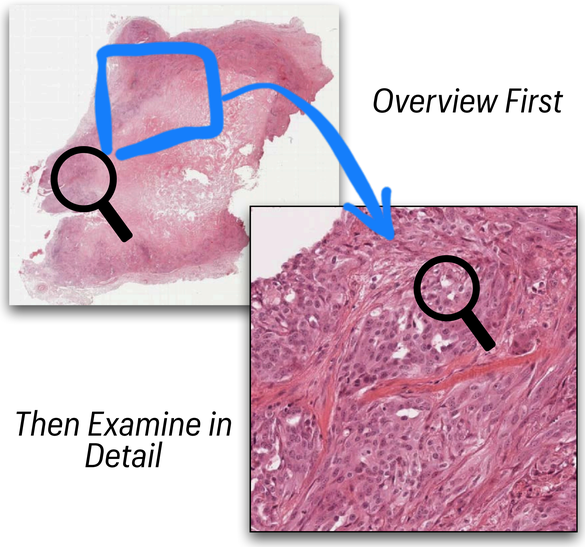
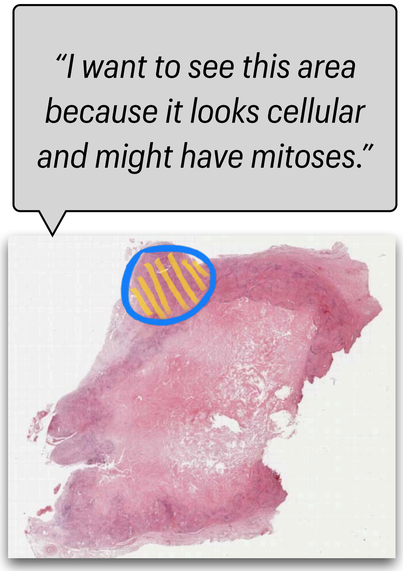
Formative Study

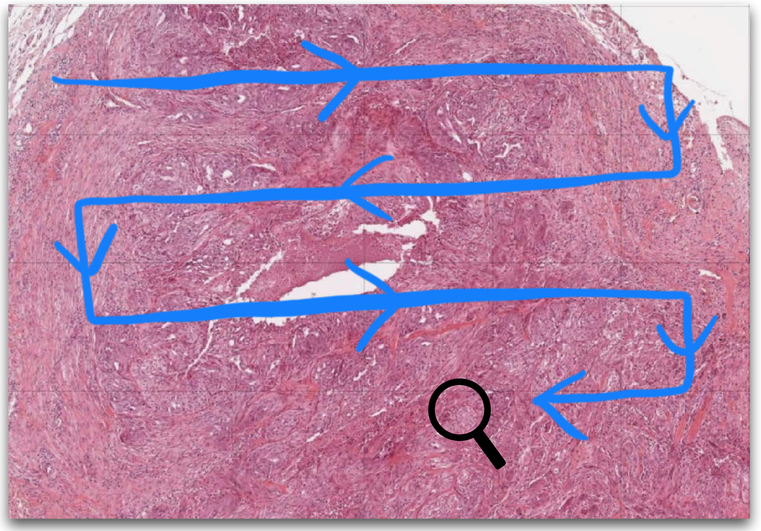
Findings



O1: Overview first, then examine in detail



O2: Use macroscopic patterns to locate ROIs in the low magnifications



O3: Search systematically in high magnifications

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Formative Study & Design

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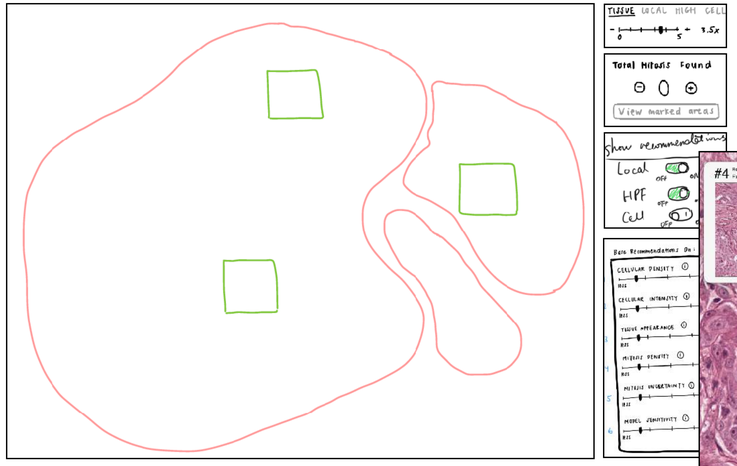
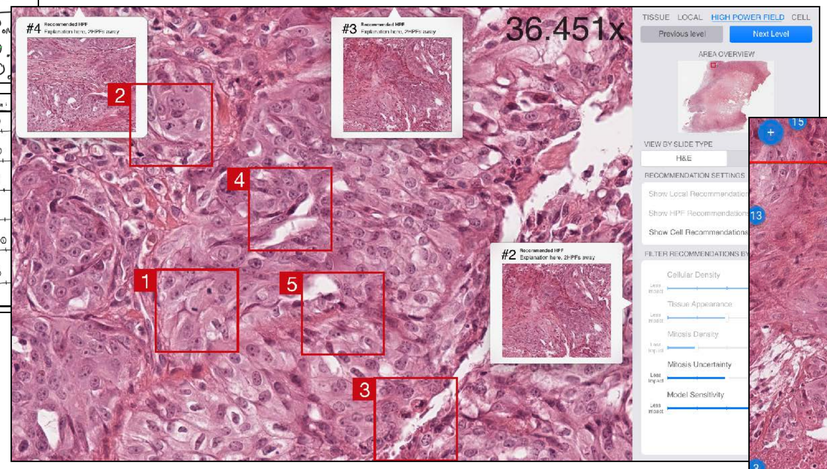
Design of NaviPath

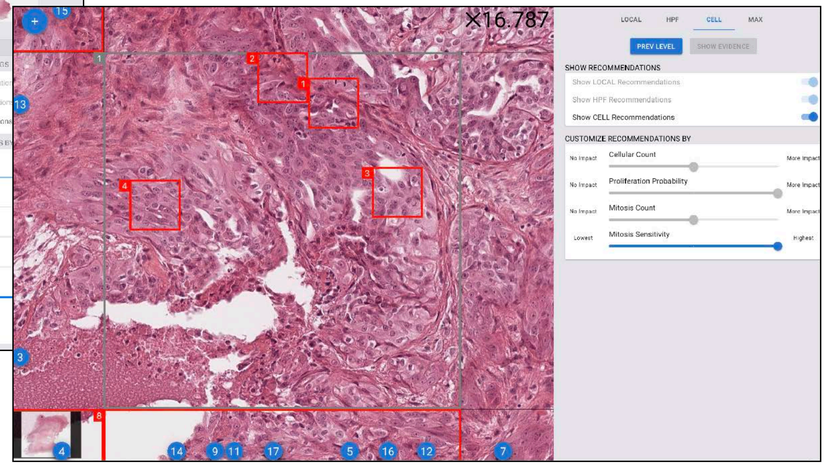
Design Iterations



#1: Low Fidelity prototype



#2: High Fidelity prototype



#3: NaviPath

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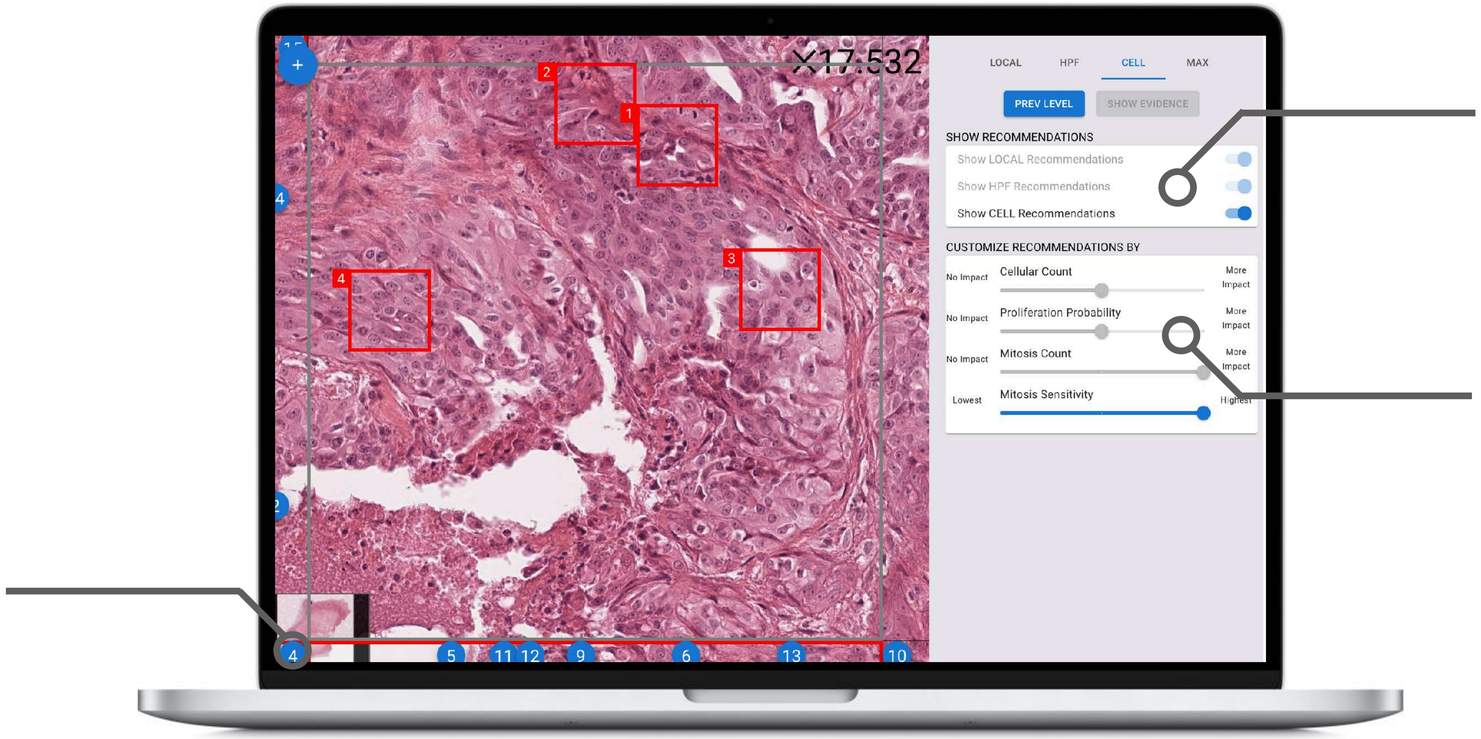
Design of NaviPath

NaviPath Components



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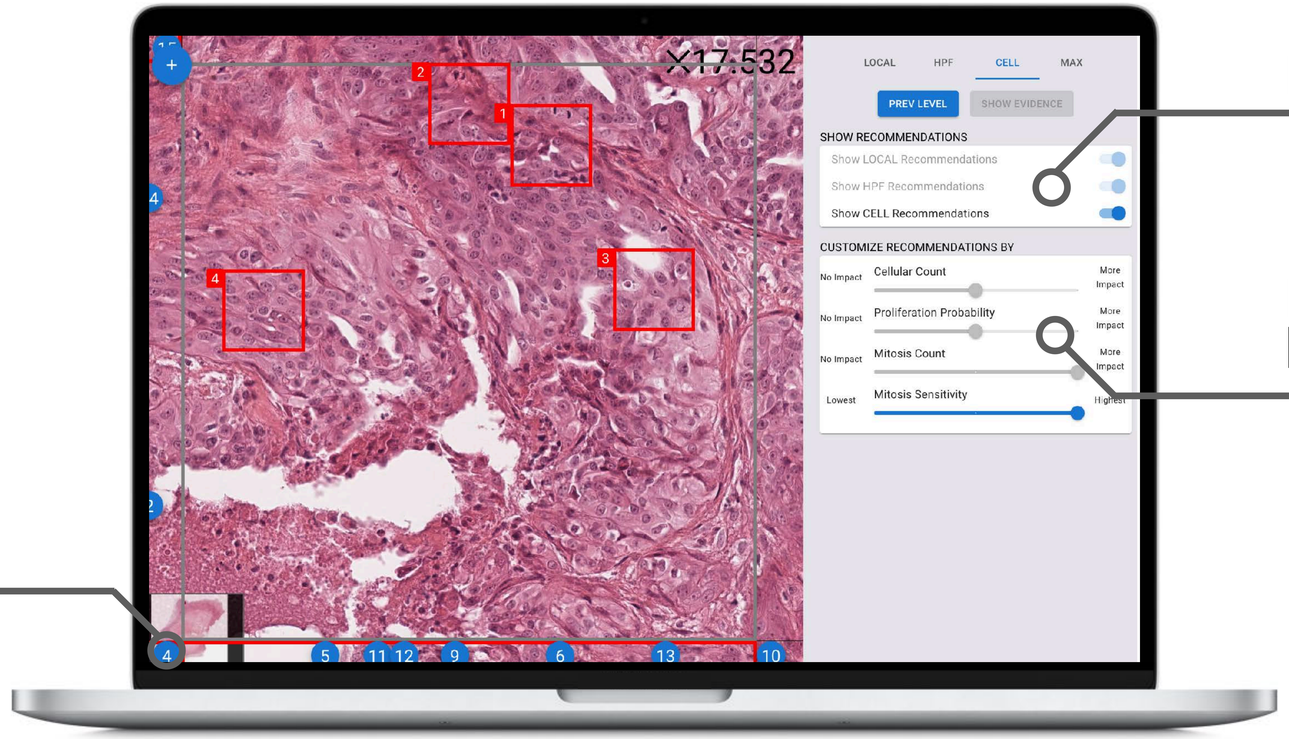
Design of NaviPath

NaviPath Components

#1: Hierarchical AI Recommendations

#2 Customizable Recommendations by Multiple Criteria

#3: Cue-Based Navigation for High Magnifications



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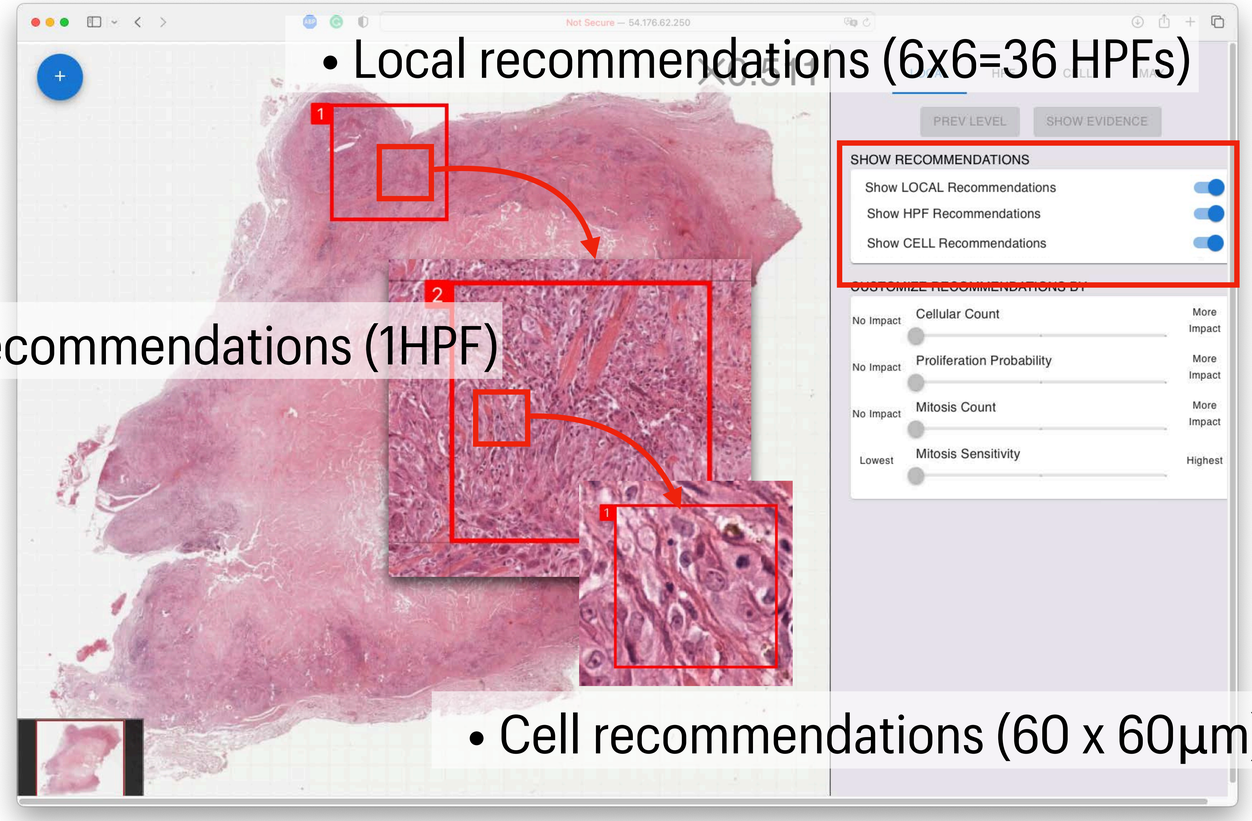
Design of NaviPath

Hierarchical AI Recommendations



- Local recommendations (6x6=36 HPFs)
- HPF recommendations (1HPF)
- Cell recommendations (60 x 60µm)

* 1HPF=420 x 420µm

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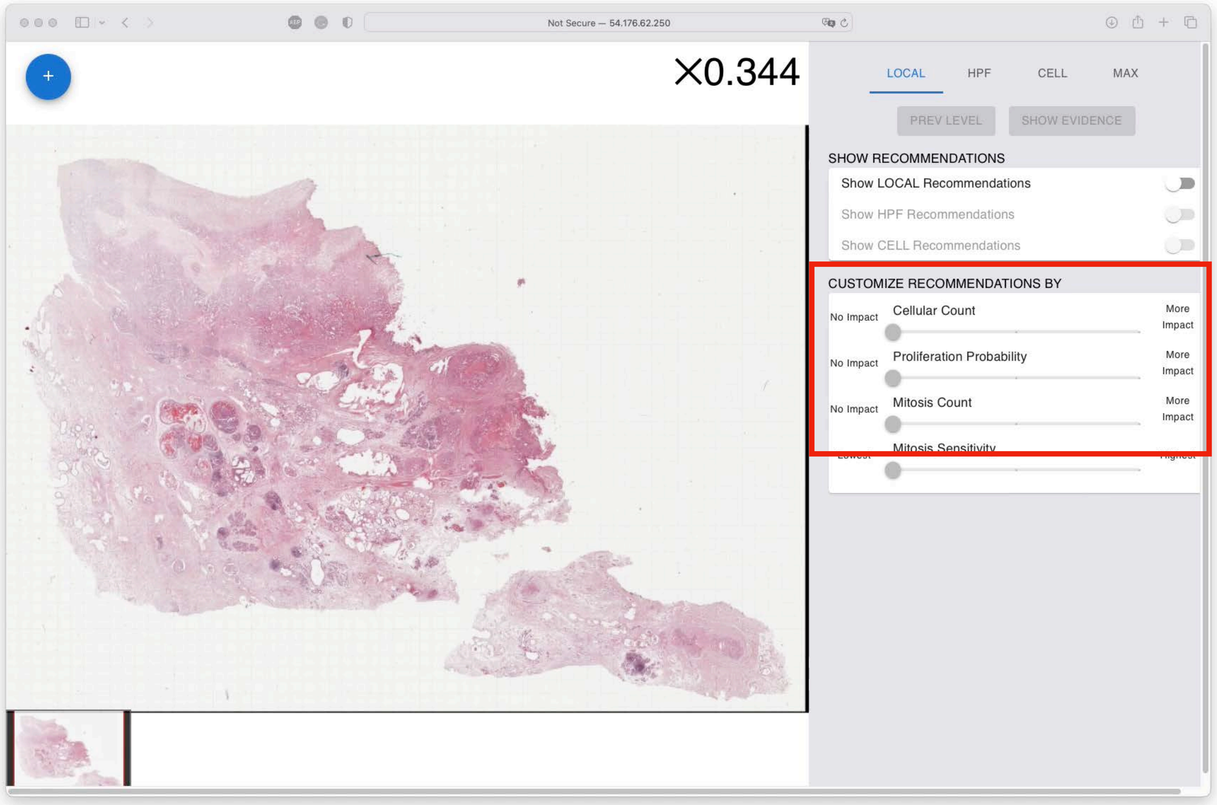
Design of NaviPath

Customizable Recommendations by Multiple Criteria



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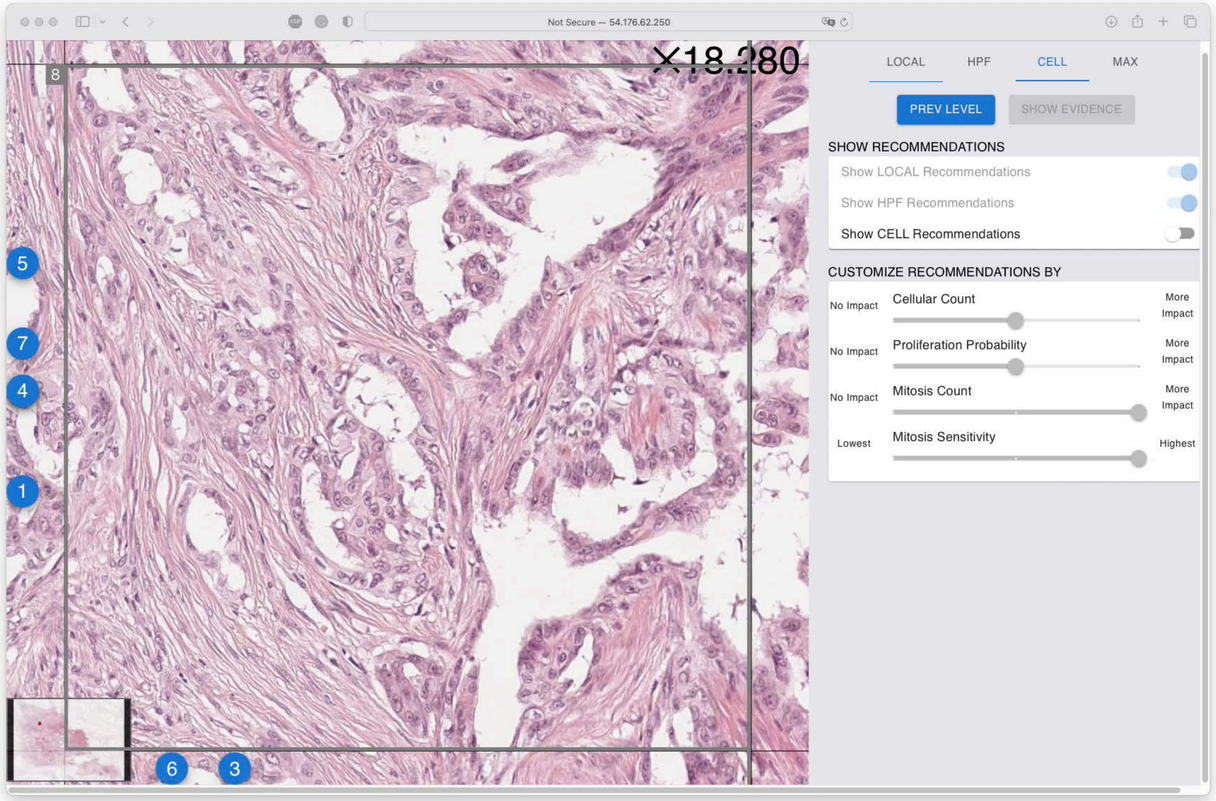
Design of NaviPath

Cue-Based Navigation



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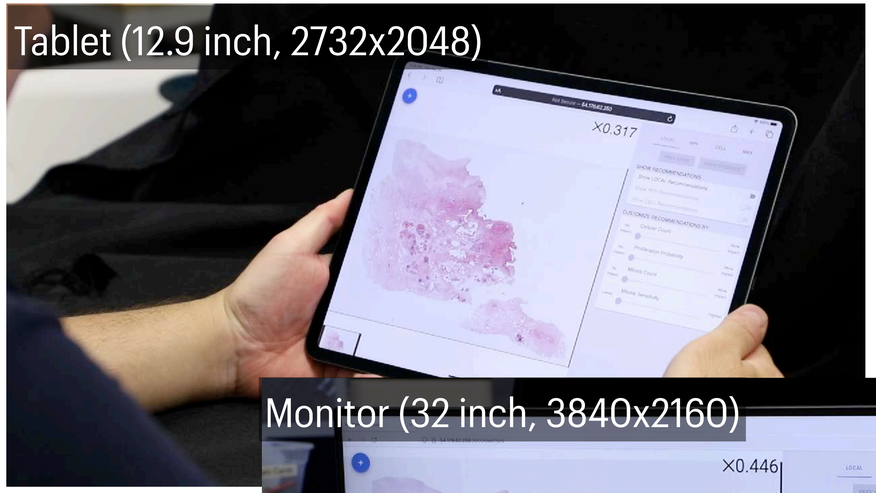
Design of NaviPath

Implementation



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Evaluation & Results

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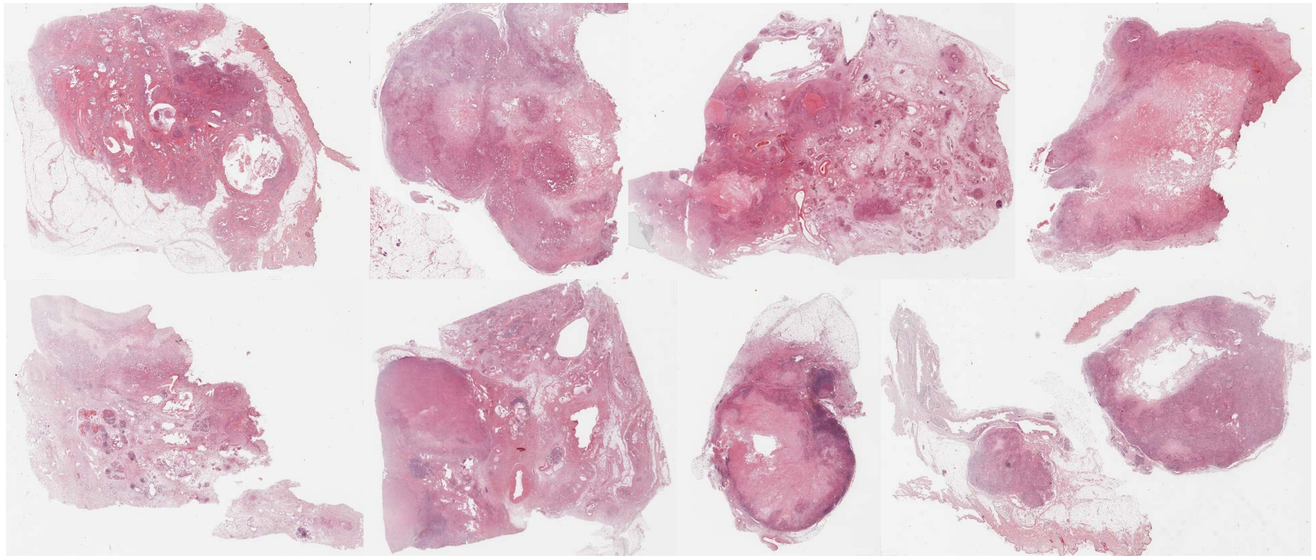
Evaluation Study

Data & Protocol



Aubreville, Marc, et al. "A completely annotated whole slide image dataset of canine breast cancer to aid human breast cancer research." Scientific data 7.1 (2020): 417.

Task

- Evaluate pathological pattern of mitosis;
- Mitosis dimension: ~10µm (~40 pixels);

Test Data

- Eight pathology scans from canine mammary carcinoma (two tutorial + six test);
- Average size: 7.15 x 10^9 pixels (~2600 HPFs);
- Average prevalence rate: 0.164/HPF (~400 per scan);

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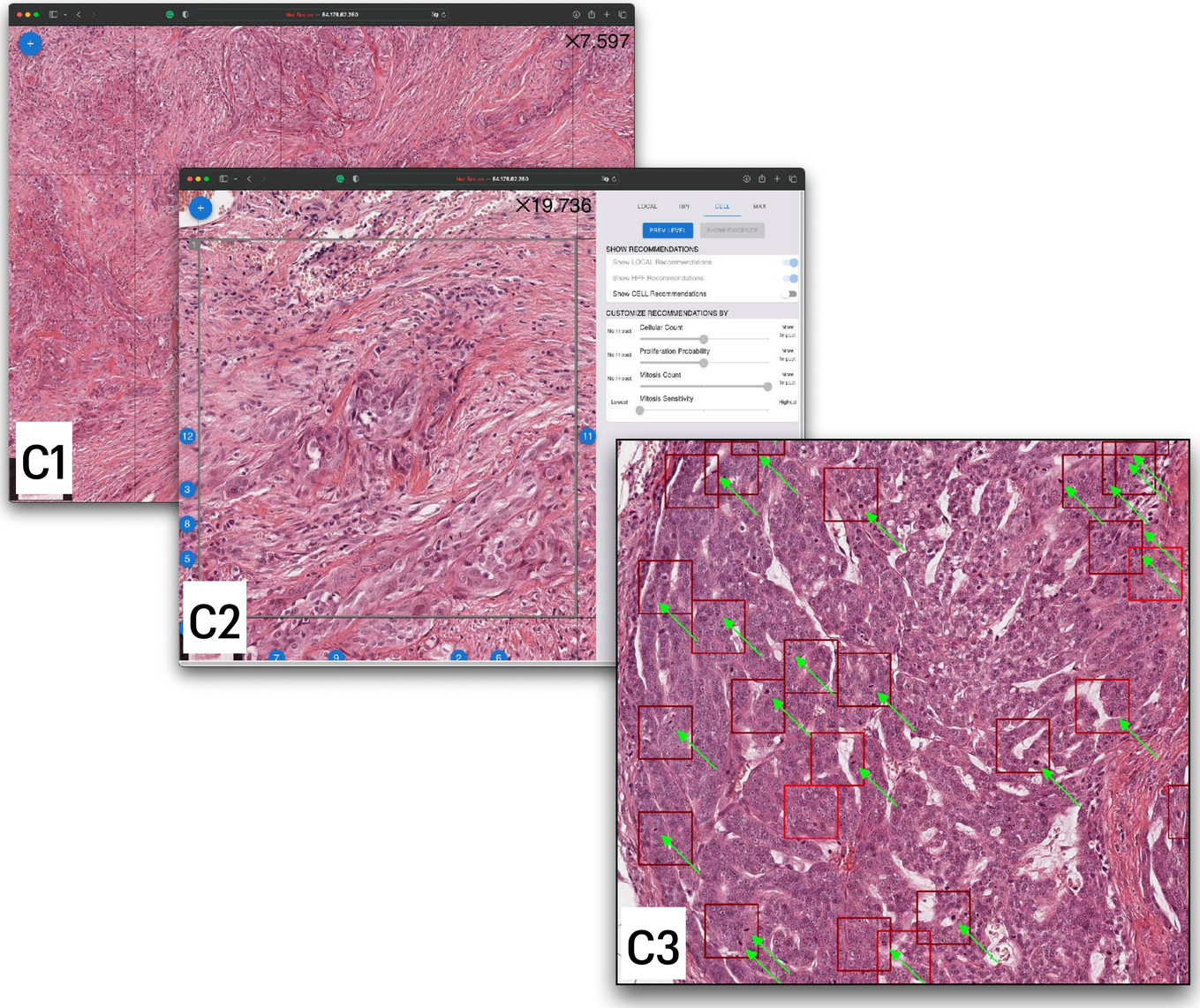
Evaluation Study

Participants & Test Conditions

- 15 medical professionals in pathology;
- Five medical centers across two counties;
- Average experience: 3.47 years (SD=0.88)

- C1: Manual examination (Human-only)
- C2: NaviPath (Human + AI)
- C3: AI-automatic reporting (AI-only)



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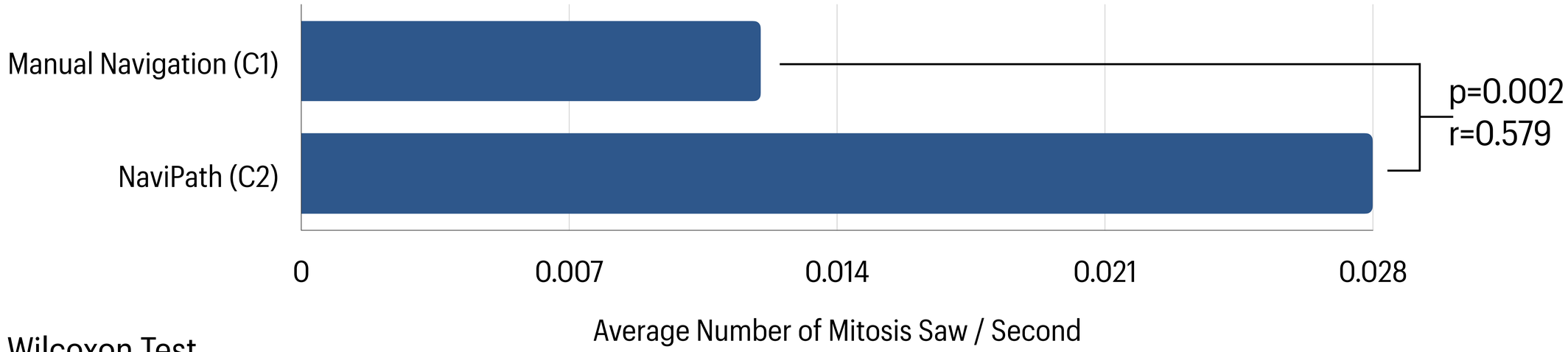
Evaluation Study

Results: Navigation Efficiency

- **Measure:**
  - Average mitosis count the participant see per unit time (second)
- **Result**
  - Participants achieved significant* higher efficiency with NaviPath



* Wilcoxon Test

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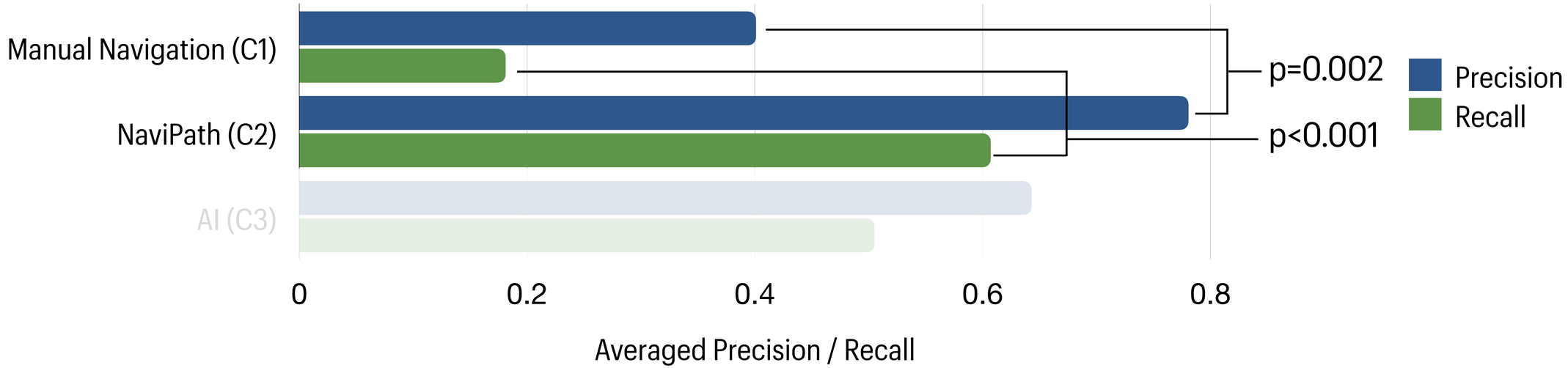
Evaluation Study

Results: Precision & Recall

- **Measure:**
  - Precision and recall in identifying mitoses
- **Result**
  - Participants achieved significant* higher precision and recall with NaviPath, compared to the manual navigation



* Kruskal-Wallis H-test + post-hoc Dunn's test with Bonferroni correction (α=0.05).

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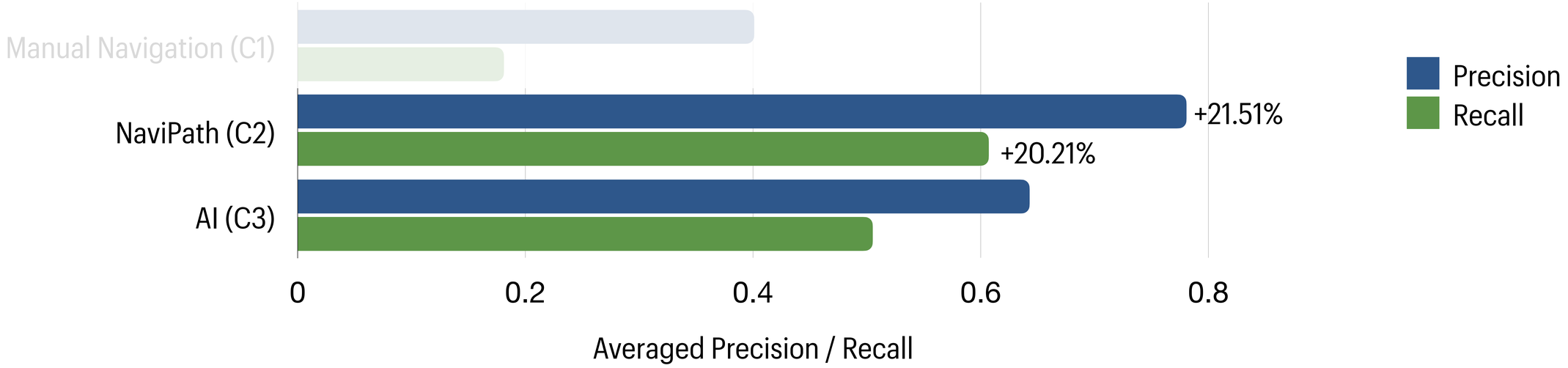
Evaluation Study

Results: Precision & Recall

- **Measure:**
  - Precision and recall in identifying mitoses
- **Result**
  - Participants achieved higher precision and recall with NaviPath on average, compared to AI



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Findings & Future Works

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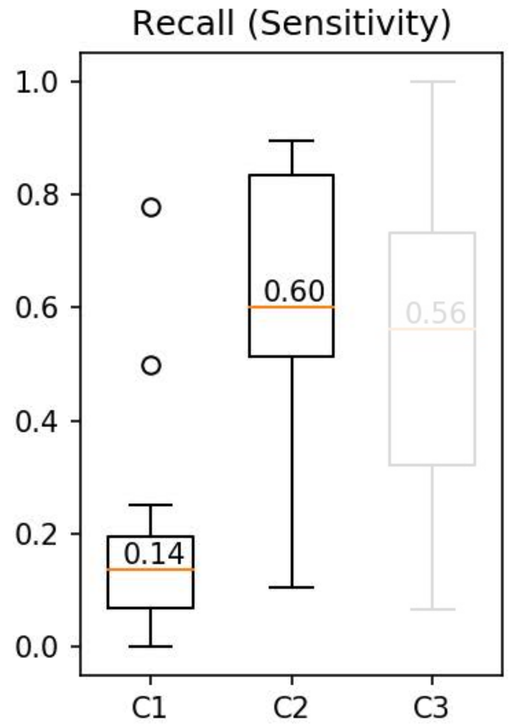
Findings

Why participants recall (sensitivity) has been improved?

- **Result from the evaluation study:**
  - Participants achieved significantly higher recall (sensitivity) in identifying mitosis (3.38X on average) with NaviPath vs. the manual navigation;
  - **Potential explanation:**
    1. NaviPath recommendations have higher prevalence rates of mitoses:
       (a) Manual navigation: 0.167/HPF
       (b) NaviPath: 1.196/HPF (6.17X higher)



Wolfe, Jeremy M., et al. "Low target prevalence is a stubborn source of errors in visual search tasks." Journal of experimental psychology: General 136.4 (2007): 623.

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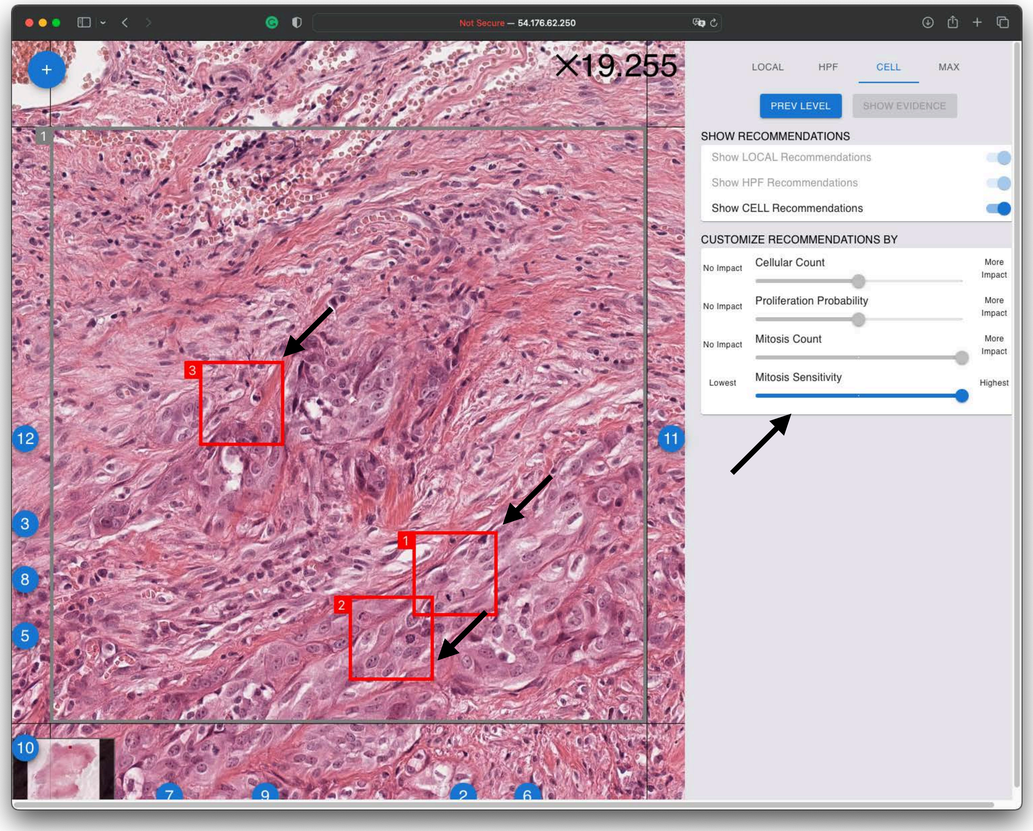
Findings

Why participants recall (sensitivity) has been improved?

- Result from the evaluation study:
  - Participants achieved significantly higher recall (sensitivity) in identifying mitosis (3.38X on average) with NaviPath vs. the manual navigation;
- **Potential explanation:**
  2. NaviPath recommendations with high sensitivities:
     (a) Changed doctors' task from visual search to verification;
     (b) Doctors can rule out false-positive recommendations quickly.



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Future Works

- Make recommendations more predictable;
- Support self-defined regions of interests added by pathologists;
- Improve navigation cues by illustrating more information to pathologists.

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