SimulDx: A Visual Diagnostic Twin Framework for Safe, Fast, and Cost-Effective Clinical Reasoning

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Abstract

Current AI diagnostic systems focus on text-based reasoning but lack visual, interactive representations of the patient and diagnostic process. This limits transparency, training utility, and the ability to simulate alternatives before real-world testing.
We propose **SimulDx**, a novel framework that creates a **visual diagnostic twin**—a virtual patient avatar that can be tested non-invasively using simulated labs, imaging, and treatments. By mimicking real-world diagnostic steps in a virtual environment, SimulDx empowers clinicians, educators, and patients to experiment with differential diagnoses and potential treatments in a **safe, fast, and low-cost sandbox**.
SimulDx integrates visual modeling, AI reasoning loops, and cost-conscious orchestration to deliver a dynamic simulation of clinical decisions. It is not meant to replace real diagnostics but to **augment decision-making**, **avoid unnecessary tests**, and potentially accelerate treatment pathways through rapid what-if exploration.
This whitepaper outlines the system architecture, clinical motivation, and potential integration with existing digital twin and AI diagnostic tools, offering a clear roadmap toward interactive, explainable, and accessible virtual diagnostics.

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1. Introduction

In clinical practice, diagnosis is rarely a one-shot answer. It’s an evolving conversation—between doctor and patient, test and intuition, probability and urgency. Yet most AI diagnostic tools today reduce this complexity to a static query: "Given this data, what’s the diagnosis?"

This simplification omits two vital elements:

1. The **process** of diagnostic refinement through step-by-step testing and reasoning.
2. The **visual and physiological evolution** of a patient's condition in response to new findings or treatments.

This paper introduces **SimulDx**, a system that lets you see, simulate, and safely test diagnostic decisions using a **virtual patient twin**. Imagine a cartoon or semi-realistic avatar representing the patient on screen. You suspect pneumonia? Run a virtual chest X-ray. Trying to differentiate flu from bacterial infection? Simulate both with lab panels and observe the changes.
SimulDx blends this **visual interactivity** with the kind of multi-agent AI orchestration pioneered by MAI-DxO (Nori et al., 2025)—using different roles like Dr. Hypothesis, Dr. Stewardship, and Dr. Challenger to balance diagnostic confidence with cost and evidence.

This framework has broad implications:

- For **education**: trainees can test their hypotheses safely.
- For **telemedicine**: patients could simulate their symptoms pre-visit.
- For **global health**: simulate outcomes in low-resource settings without equipment.
- And for **clinical planning**: fast-forward treatments to predict effect trajectories.

What SimulDx offers is not a replacement for medical judgment, but a **visual reasoning partner**—a digital "sandbox" where medicine can be practiced with the rigor of simulation and the safety of abstraction.

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2. Background & Motivation

Medical diagnostics remain one of the costliest and most variable domains of healthcare delivery. A 2023 CMS report indicated that over 30% of diagnostic spending may be avoidable (Mandl, 2025). Simultaneously, clinical errors due to premature diagnostic closure continue to impact outcomes, especially in primary care and emergency medicine.

The emergence of large language models (LLMs) like GPT-4, Claude, and Gemini has enabled high-accuracy text-based diagnosis (McDuff et al., 2025). However, these systems often operate on static prompts and do not reflect the stepwise, iterative nature of real clinical reasoning.

Recent work such as the **MAI-DxO orchestrator** introduced by Microsoft Research demonstrates how structured role-based AI agents can outperform physicians in diagnosis by guiding the model to ask sequential questions and weigh cost vs yield (Nori et al., 2025).

Simultaneously, the rise of digital twin technology—especially in cardiovascular modeling and pharmacokinetics—has shown that simulated patients can reduce unnecessary tests, enable virtual trials, and personalize care (Wennberg et al., 2008; VPH Institute, 2024).

However, what's missing is a convergence: a system that:

- Allows **interactive, visual exploration** of diagnostic pathways
- Is **testable and intuitive** for clinicians and learners
- Incorporates **AI reasoning with dynamic visual feedback**
- Supports **cost-aware experimentation** before real-world action

SimulDx fills this gap.

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3. System Overview

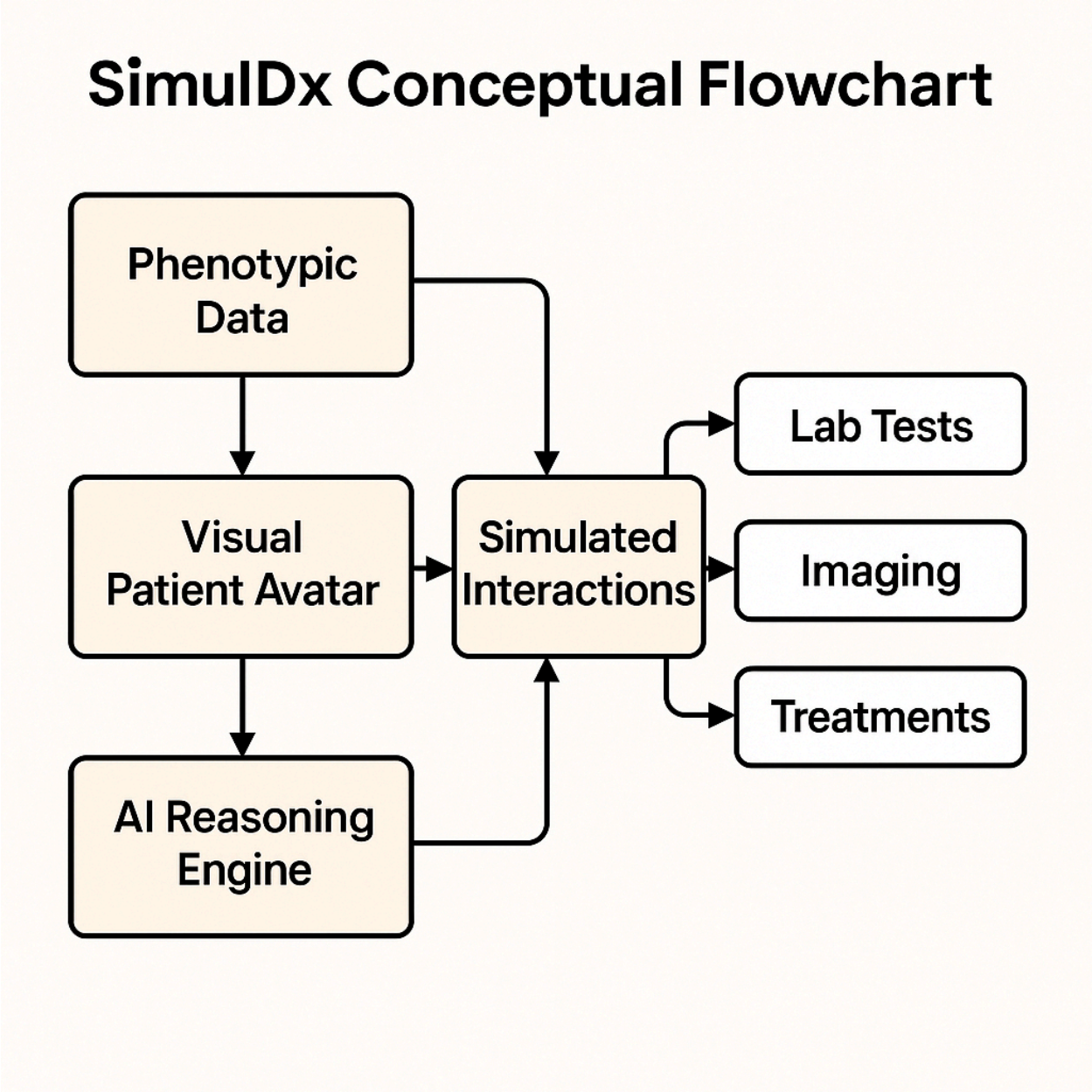

Figure 1: Conceptual flowchart showing SimulDx system components and data flow.

SimulDx consists of four key components:

3.1 Visual Avatar Engine

- Renders a 2D or 3D representation of the patient.
- Reflects symptoms (e.g. jaundice, rash, labored breathing) and changes over time.

3.2 Virtual Test Interface

- Simulates lab tests (CBC, LFTs), imaging (CT, X-ray), physical exams.
- Draws on structured knowledge bases and probabilistic logic to generate plausible results.

3.3 AI Reasoning Core

- Uses an MAI-DxO-style panel with multiple agent roles:
    - Dr. Hypothesis (tracks differential)
    - Dr. Test-Chooser (selects high-yield investigations)
    - Dr. Challenger (mitigates bias)
    - Dr. Stewardship (monitors cost/invasiveness)
    - Dr. Checklist (ensures safety/completeness)

3.4 Outcome Simulation Module

- Allows simulated treatments (e.g., give antibiotic, observe fever reduction).
- Can fast-forward time to project outcomes.

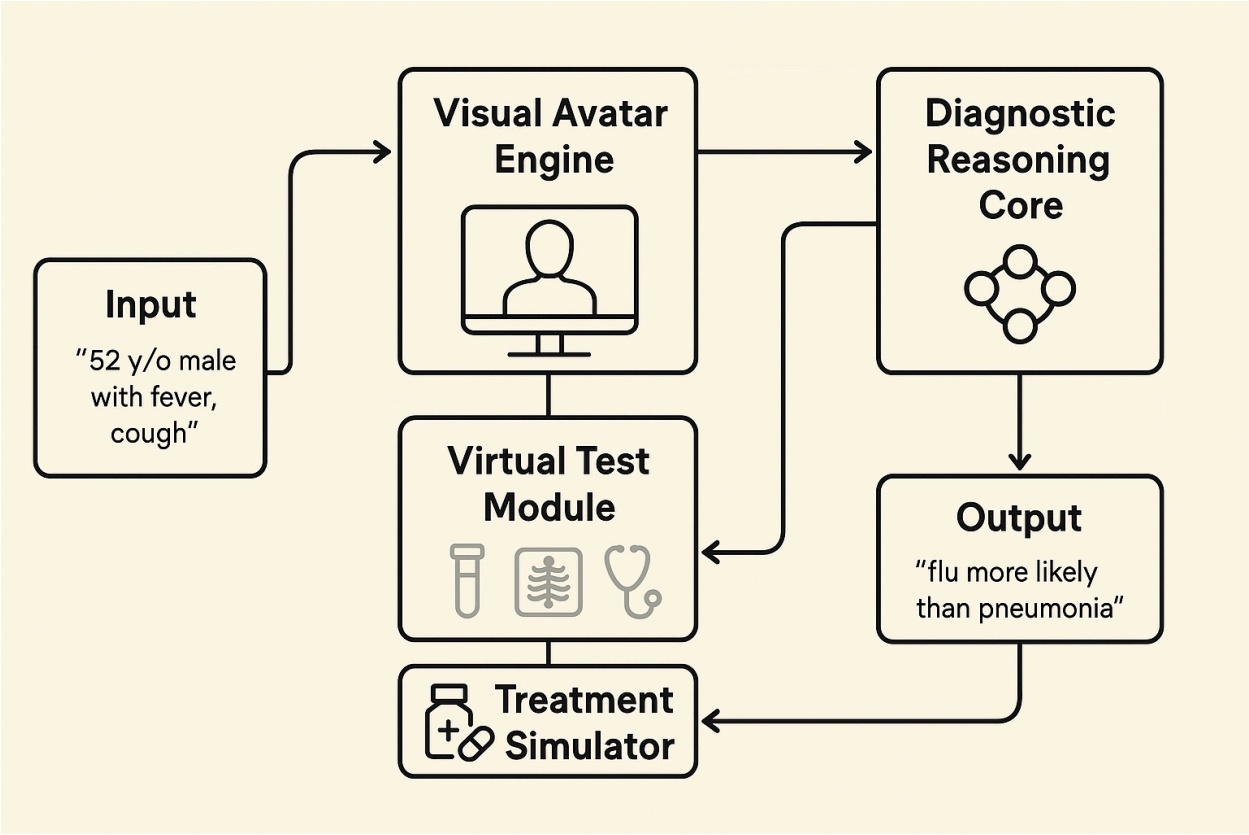

Figure 2: Visual walkthrough of a clinical use case using SimulDx, illustrating symptom input, AI panel discussion, virtual test selection, and simulated treatment outcome.

4. Future Directions

- Expand avatar realism with physiological animation libraries
- Integrate pharmacokinetic AI models for treatment simulation
- Enable patient-generated avatars from symptom checkers or EHRs
- Deploy as a teaching tool or diagnostic assistant in telemedicine

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5. Risks & Limitations

- Not yet validated for clinical decision-making
- Risk of over-trusting simulations without real-world context
- Bias in training data may affect accuracy of test logic
- Requires careful UI/UX design to avoid oversimplification

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6. Industry Landscape & Additional References

Several companies and institutions are actively working on components or adjacent technologies that align with the SimulDx vision:

AI Diagnosis Systems:

- **Microsoft Research** – MAI-DxO (AI doctor panels for sequential diagnosis)
- **Google DeepMind** – Med-PaLM (clinical QA and differential diagnosis)
- **Hippocratic AI** – Safety-first LLMs for healthcare communication

Digital Twin Technology:

- **Siemens Healthineers** – Cardiovascular and organ-level digital twins
- **Dassault Systèmes** – Living Heart Project, virtual patient platforms
- **Philips** – Patient digital twin pilot programs for ICU decision support

Visual and Simulation Platforms:

- **Body Interact** – Interactive virtual patients used for clinical training and decision-making in medical education settings. Unlike SimulDx, it focuses on predefined case scenarios rather than dynamic, AI-driven test simulations.

- **Babylon Health / K Health** – Symptom checkers with visual outputs
- **VisualDx** – Dermatological and symptom-based decision visuals
- **Unreal Engine (Epic Games)** – Powering medical training avatars and immersive VR/AR simulation environments for healthcare education.

These organizations may serve as potential collaborators, benchmarks, or dissemination pathways for SimulDx research and prototype development

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References

- Nori, H. et al. (2025). *Sequential Diagnosis with Language Models*. arXiv:2506.22405
- McDuff, D. et al. (2025). *Towards accurate differential diagnosis with large language models*. Nature.
- Mandl, K. (2025). *How AI could reshape health care*. JAMA.
- Wennberg, J. et al. (2008). *Improving quality and curbing healthcare spending*. Dartmouth Atlas.
- VPH Institute (2024). *Virtual Physiological Human Initiative*. vph-institute.org

Technical Scope

✅ What SimulDx *Can Be Used For Today*

Area	Example Scenarios
Respiratory	Flu vs pneumonia vs Covid
Gastrointestinal	Appendicitis vs IBS vs food poisoning
Infectious disease	Fever: malaria vs typhoid vs dengue
Pediatrics	Rash: allergy vs viral exanthem
Neurology	Headache: tension vs migraine

🚧 What's Grey or Experimental

- Oncology (cancer modeling)

- Cardiology (real-time vitals + ECG)
- Trauma (surgical response modeling)
- Pharmacogenomics (drug metabolism)

SimulDx focuses on **functional credibility**, not full genetic modeling.
