PERSEUS: enhancing mobile ultrasound with pattern recognition capabilities

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Rationale

Ultrasound imaging (US) stands out as one of the most cost-efficient, and therefore, ubiquitous diagnostic technologies in the medical domain. Nonetheless, US diagnostic value is determined by both image quality and the expertise of the clinician performing the scan. As image quality deteriorates due to constraints such as hardware power, distance of the probe to the organ of interest, and the accuracy of hardware and software elements, clinical interpretation becomes a challenging cognitive task which increases the time and amount of training required by clinicians to become proficient [1,2].

Current research focuses on the employment of machine learning methods to assist medical pattern recognition in US. However, computational requirements associated with these methods (data transformation, feature extraction, employment of GPUs, etc.) reduce the scope of their applicability in the clinical practice, particularly in low-power, mobile scanners.

Our work investigates the role of machine learning in ultrasound image interpretation.

Our goal is to enhance mobile ultrasound scanners with pattern recognition capabilities to perform well-defined perceptual tasks of clinical value (Figure 1).

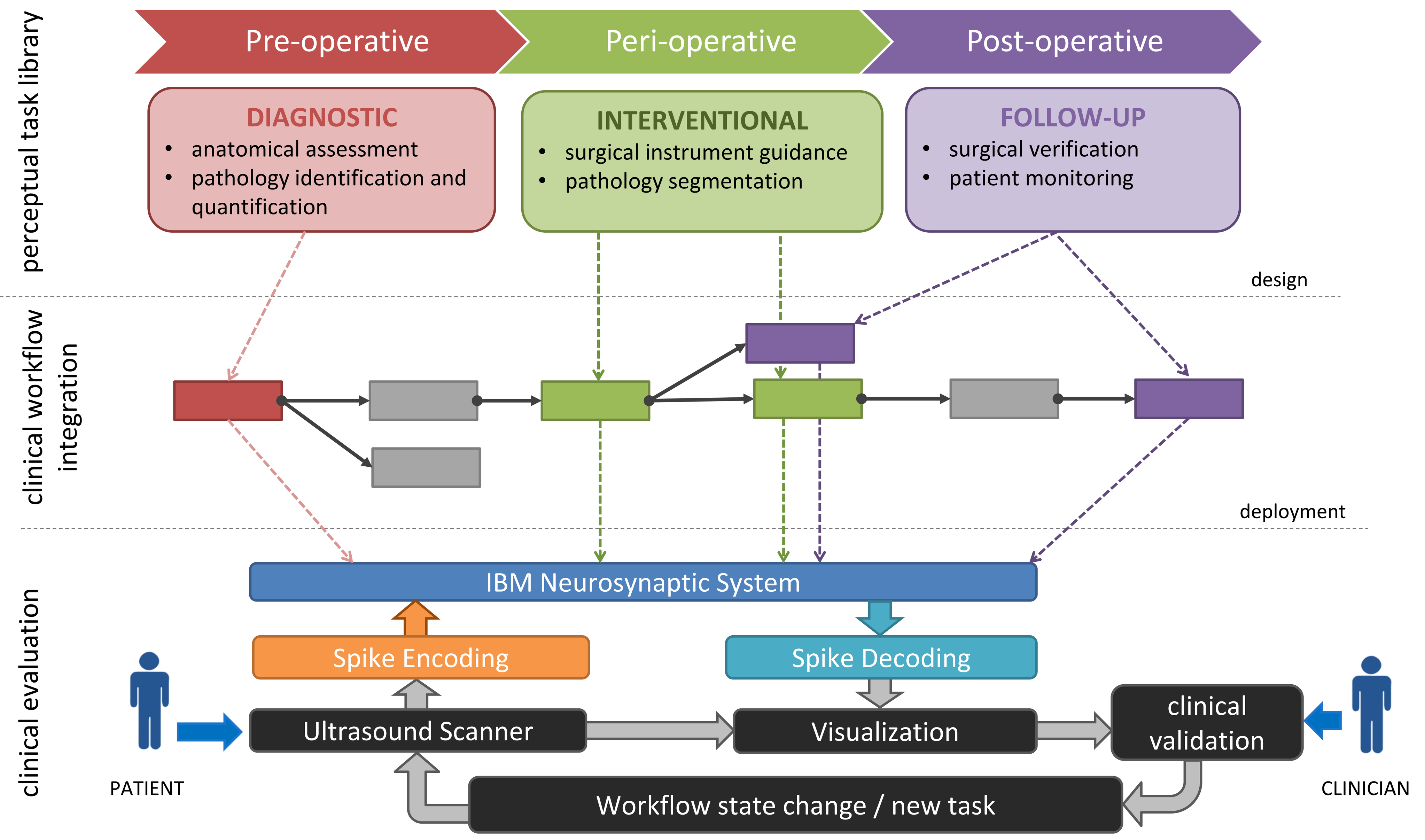

Figure 1. ***PERSEUS framework***. *Perceptual tasks in the framework can be diagnostic, interventional or follow-up; Tasks are selected from the library to build clinical workflows (i.e. spinal injection procedure); PERSEUS deploys tasks onto IBM's neurosynaptic system (TrueNorth) keeping track of the current workflow state. Once the task is finalized/verified by the clinician, the state changes and new tasks are deployed onto TrueNorth.*

Methods and Materials

As the first application of PERSEUS (perceptive ultrasound framework) we selected ultrasound-guided spinal injection procedures as our proof of concept.

Examples of such procedures include:

- Spinal taps: cerebrospinal fluid is drawn from the spine to be tested for the presence of bacteria
- Epidural injections: anesthesia is delivered to expecting mothers to aid with the delivery process.

Spinal Phantom

An anatomically-correct plastic model of the lumbar spine was manufactured using a 3D rapid prototyping printer (Figure 2).

Figure 2. ***Spinal phantom***. *Four tissue types were simulated: spinal chord, ligamentum flavum, fat and skin.*

Surface models of joints L1 to L4 were derived from manual segmentation of a patient CT, and housed on a custom plate to preserve the natural spacing and curvature of the vertebral column [3].

Framework Elements

A. Perceptual tasks:

Each of these tasks defines a step in the spinal injection workflow (paramedian epidural access approach) [4].

- Cauda equina (horse's mane) identification
- Detection of spinous process L5
- Detection of spinous processes L2-L3, L3-L4
- Transversal processes identification
- Articular processes identification
- Dura and sub-dural visualization
- Selection of optimal plane for needle insertion

B. Clinical workflow integration:

Each one of these scenarios can be addressed by training/testing an artificial neural network (ANN). Enabled by an early research prototype evaluation agreement, IBM Research is providing access to IBM's Neurosynaptic System [5], a low power chip for native, real-time execution of neural algorithms. Trained ANNs, one per each perceptual task can be deployed onto IBM's chip in the form of **corelets** [6].

C. Clinical evaluation:

PERSEUS controls when corelet deployment occurs depending on the current state of the workflow and upon receiving validation by the clinician performing the procedure.

Increased cognitive load: from 3D anatomical knowledge to 2D sono-anatomy

Transferring clinician's anatomical knowledge to 2D US images *is not intuitive*. Spatial relationships among anatomical structures that are trivial in 3D become subtle or even non-existent in 2D US (Figure 3). This is the reason why 3D perceptive tasks need to be decomposed in simpler, sequential steps.

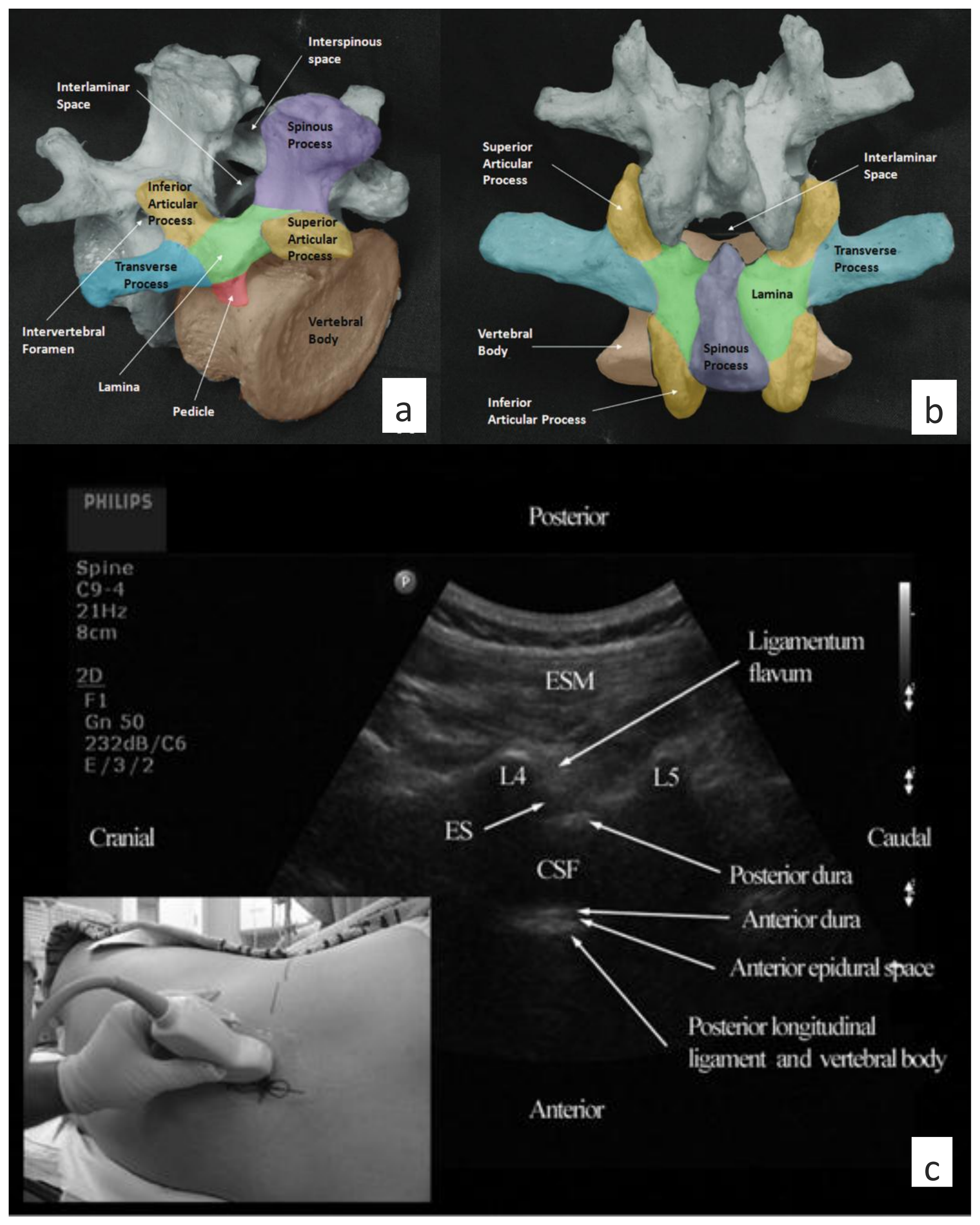

Figure 3. ***3D anatomy vs. 2D sono-anatomy***. *(a) and (b) show an annotated spinal model [7] (c) shows that sono-anatomy is dependent of the acquisition plane and thus off-plane spatial relationships are lost [4].*

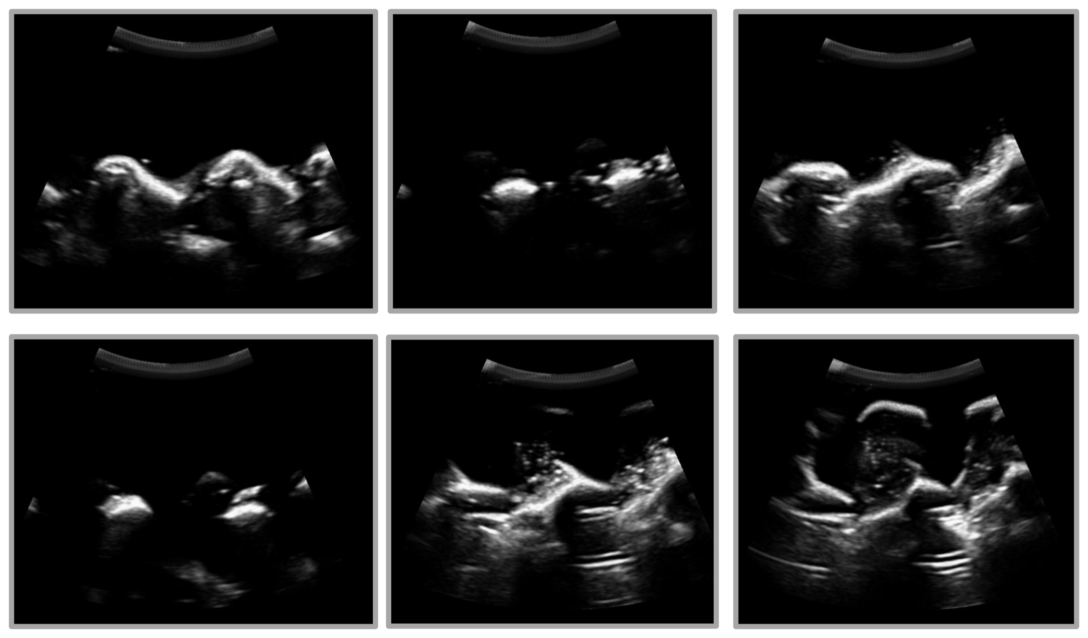

Figure 4. ***Spine phantom US images***. *In this image set the spinous, articular and transverse processes are visible, can you identify them using the 3D model from Figure 3?*

Discussion

- A perceptive US framework can assist in these tasks, enabling mobile, low-power ultrasound to perform pattern recognition.
- IBM's neurosynaptic chip can enable dynamic execution of perceptual tasks by mobile, low-power US scanners.
- Some US perceptual tasks are simpler than others for a human expert. We do not know yet which tasks require extensive training or if there are tasks that cannot be learned by an ANN (i.e. anatomical variability due to spinal malformations such as scoliosis, body fat percentage, etc.).
- Though a retinal representation might suffice in pattern recognition, classification accuracy can be improved by pre-selecting features. However, this generates additional pre-processing time. The trade-off between computational and classification performance must be evaluated for each task.

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