# Task 1

Currently, the claim driving my research work is that scoliosis quantification using ultrasound-accessible landmarks can be made more robust using machine learning techniques.

For someone familiar with the vocabulary, but not with the field, a few sub-claims could be made towards accepting this main claim:

1. Vertebral landmarks are locatable in anatomic space using tracked ultrasound.
   * [Purnama2010] demonstrated a method for using ultrasound images, with their locations relative to the patient, to construct a volumetric representation of the patient’s spinal anatomy.
   * [Purnama2010] shows images of one of their volumetric spinal representations wherein various anatomic landmarks are visible. This identifiability taken with the spatial information associated with the volume illustrate that these landmarks can be located with their method.
   * If one were to refute the validity of this study, it might be on the basis of the accuracy of the apparent locations of the landmarks. To the non-expert ultrasonographer (such as myself), ultrasound images, such as those shown by [Purnama2010], are difficult to interpret. How do we know the apparent landmark locations represent the landmarks’ actual relative locations in the patient’s anatomy? I will address this point as I discuss the work supporting my next sub-claim.
2. The locations of those landmarks can be used to quantify the severity of scoliosis – i.e. they can be used as a proxy to the gold standard, Cobb-angle, measurement.
   * Two studies which support this claim are [Chen2011] and [Ungi2014]. Both of these studies had spatially tracked ultrasound scans performed on phantom spine models. They both demonstrated that the spine’s angle of scoliotic curvature can be estimated to within clinically acceptable limits of error when the model is scanned by a skilled ultrasonographer.
     1. This brings me to the possible refutation of the previous sub-claim. Where [Purnama2010] volume models show features which correspond to landmarks of interest, their relational accuracy can still be questioned. Studies like [Chen2011] and [Ungi2014] demonstrate that whatever inaccuracies there are in anatomic volume models constructed from ultrasound, they either cancel out error in methods like these to produce the observed clinical accuracy (unlikely), or they are sufficiently small for [Purnama2010] to serve as the basis of this ongoing work, i.e. for [Chen2011] and [Ungi2014] to quantify scoliosis.
   * By comparing the angles between lines connecting the appropriate landmark points, [Chen2011] and [Ungi2014] had data to compare against ground truth angles, extracted from X-rays. The similarity between their method and ground-truth is what supports this sub-claim.
   * Like [Purnama2010], it is difficult to question the validity of these studies on the basis of the accuracy of their assumption, but the limits of their applicability can be questioned. For instance, whereas both of these studies were performed on phantom models, can the results be extended to live patients? The authors were aware that ultrasound data from live patients is more difficult to interpret than phantom data and made the prudent comment that more studies are required to extend their results to a clinical setting. Either this may become the scope of my work, or I can attempt to expand it by examining studies performed on living patients. My work, too, will not be validated in a clinical setting, but a virtual one. As such, it may be safer to limit my scope to this domain rather than try to expand it by referring to studies performed on live patients, having their own limitations and factors which limit their relevance to my work.
3. In clinical practice, the sets of landmark point locations are likely to contain several types of flaws. Namely, random noise, systematic error resulting from false-positive landmark detections, and missing points from difficulties in interpreting the images.
   * As of yet, I neither have sources to support this claim, nor a clear idea of how to test it.
   * Tentatively, I could 3D print several CT-based scoliotic spine models and compare the locations of the ground-truth CT landmarks to those located on the model by various ultrasonographers.
   * The operator-placed and ground-truth landmark locations could be compared to assess typical noise, the nature of systematic errors, and local geometric factors influencing systematically misplaced and missing point locations. It is the correspondence of the observed errors with the nature of expected errors which could support this sub-claim. This sub-claim would be adjusted to accommodate any forms of errors demonstrated which I have not considered.
   * Although one might expect information gathered from such an experiment to indicate problems which would only be greater with live patients, it is imprudent to extend such qualitative results and impossible to extend such quantitative results. This, like possible criticisms of [Chen2011] and [Ungi2014], suggests that I limit the scope of applicability of my work to proof of concept, outside of clinical practice.
4. A combination of pre-processing on the landmark point sets and the existing robustness of neural network algorithms are sufficient to provide a Cobb angle estimation more accurate than that taken directly from the operator-located points.
   * To my knowledge, no work has been done which can either substantiate or dismiss this claim. My supervisor suggested this project to me with the idea that it is a feasible investigation, as I too am beginning to see. If any work has been done to refute this claim, either it has not been published, or myself and hopefully my supervisor are simultaneously unaware of it.
   * Much work has been done on methods, neural or otherwise, to draw estimations from data with missing values and outliers, and to evaluate the sensitivity of neural networks to noise in their input. This work, performed outside the context of scoliosis quantification is insufficient to provide immediate justification for my main claim, as it relates specifically to scoliosis. Neural networks, having never been used to estimate the Cobb angle from such data, must still be shown to be capable of this, regardless of flaws in the input data. With that established, neural networks may then be shown to continue to provide output within clinically acceptable limits of error as the data becomes increasingly flawed.
   * I plan to investigate this claim by constructing a neural network which, with the use of statistical or other neural methods to deal with missing and misplaced values, is capable of estimating the Cobb angle to within clinically acceptable limits of error. For the purposes of validation, the accuracy of an estimation is the difference between it and the Cobb angle derived from a ground-truth CT scan.
   * By demonstrating the applicability of neural networks for the data which has been degraded to simulate likely error in ultrasound-collected, we fall back on my last claim about such errors being likely in real ultrasound data.
   * Since my landmark location data will come from artificially degraded points located using CT, a foreseeable criticism of my work is either I did not properly simulate one of the types of error expected in ultrasound, or else I failed to consider some. The only way I can imagine defending against such a criticism is for it to be untrue. I will have to make sure my error simulation is accurate and exhaustive.

# References

[Chen2011] W. Chen, E. H. M. Low, and L. H. Le, “Using Ultrasound Imaging to Identify Landmarks in Vertebra Models to Assess Spinal Deformity”, 33rd Annual International Conference of the IEEE EMBS 2011.

[Purnama2010] K. E. Purnama, M. H. F. Wilkinson, A. G. Veldhuizen, P. M. A. van Ooijen, J. Lubbers, J. G. M. Burgerhof, T. A. Sardjon, and G. J. Verkerke, “A framework for human spine imaging using a freehand 3D ultrasound system”, Technology and Health Care 2010; 18:1-17.

[Ungi2014] T. Ungi, F. King, M. Kempston, Z. Keri, A. Lasso, P. Mousavi, J. Rudan, D. P. Borschneck, and G. Fichtinger, “Spinal Curvature Measurement by Tracked Ultrasound Snapshots”, Ultrasound in Medicine and Biology 2014; 40(2):447-454.