Feedforward Neural Networks can capture Human-like Perceptual and Behavioral Signatures of Contour Integration

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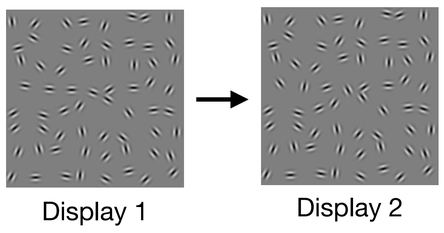
PHENOMENA

The perceptual system takes pixelated input and constructs representation of extended contours/shapes

PSYCHOPHYSICAL TASK



Display 1 → Display 2

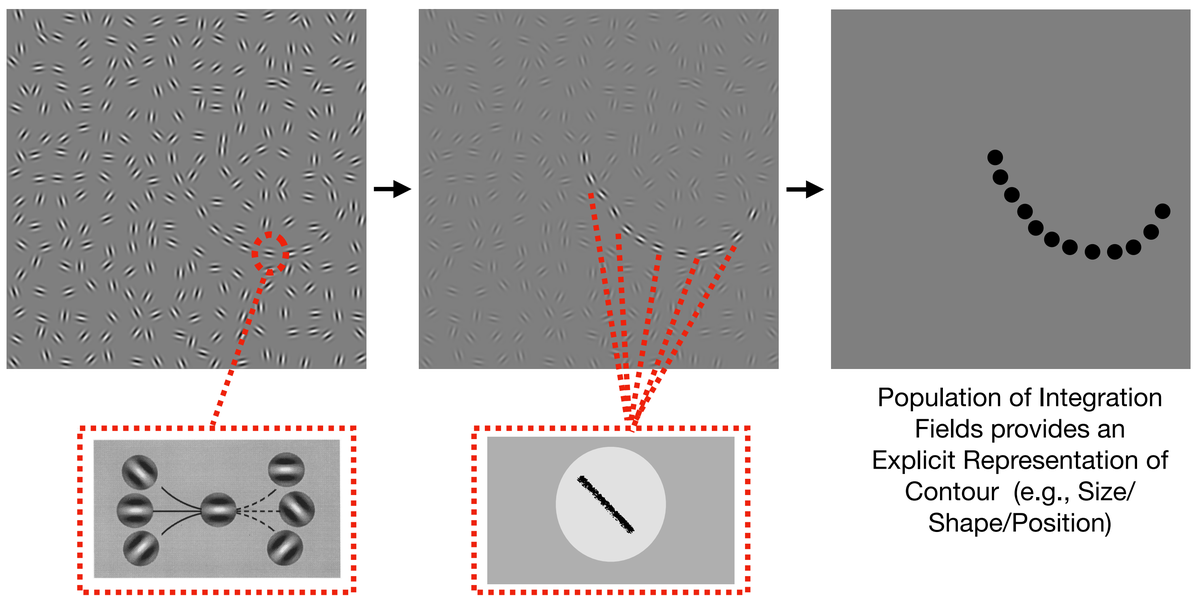
Which display had a contour?

Field, Hayes & Hess, 1993

Easy (smooth global path, elements aligned with global path) > **Medium** (crooked global path, elements aligned with global path) > **Hard** (crooked global path, elements misaligned with global path)

PROPOSED MECHANISM

Early Stage Mechanisms → **Mid-Late Stage Mechanism** → **Contour Representation**



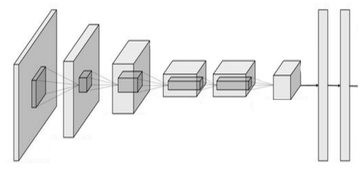
Association Fields (AF)
Units Amplify Responses to Local Elements With Smooth Collinear Neighbors

Integration Fields
Units with Large-Elongated Receptive Fields Integrate Local Responses

Population of Integration Fields provides an Explicit Representation of Contour (e.g., Size/ Shape/Position)

QUESTION

To what degree are the 'contour perception' signatures a reflection of early AF-like units vs. relatively mid-late stage integration units?



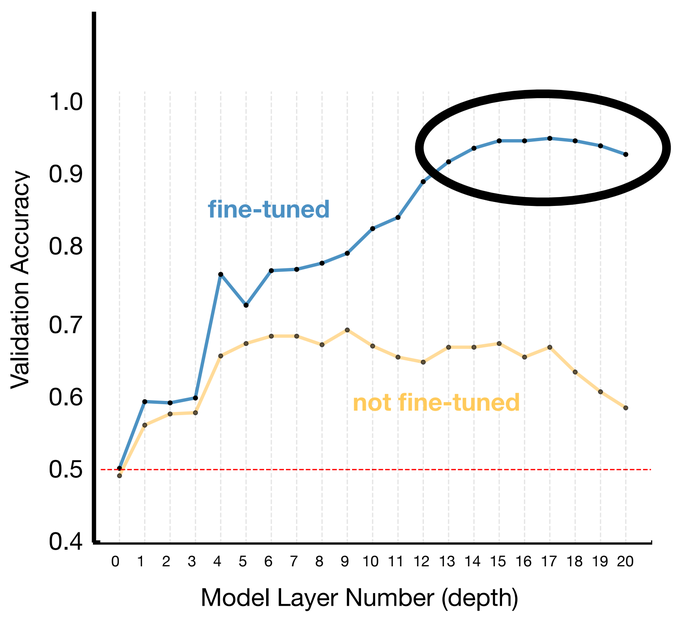
Can features of early/mid/late-stage of a DNN be used to do contour integration?

If so, what inductive biases are required to show human-like signatures of contour integration?

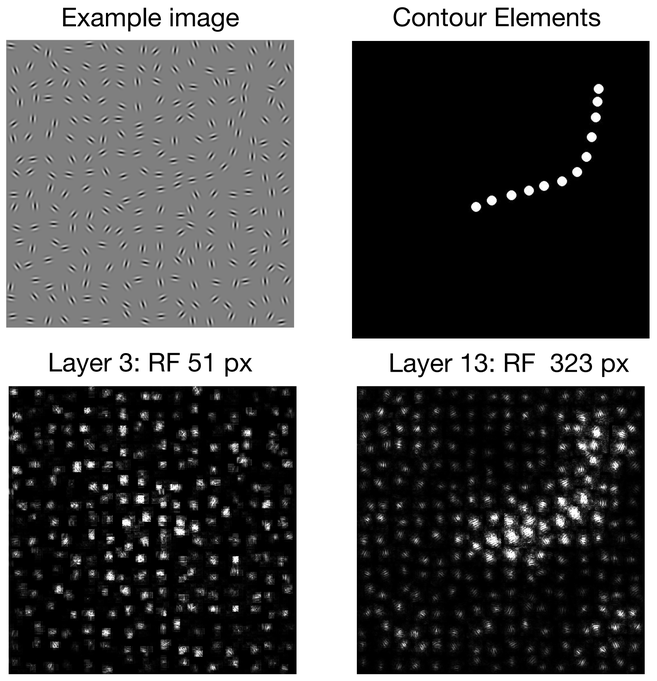
e.g., sensitivity to global path curvature or local element alignment with global path?

Large Receptive Fields Are Required for Contour Integration

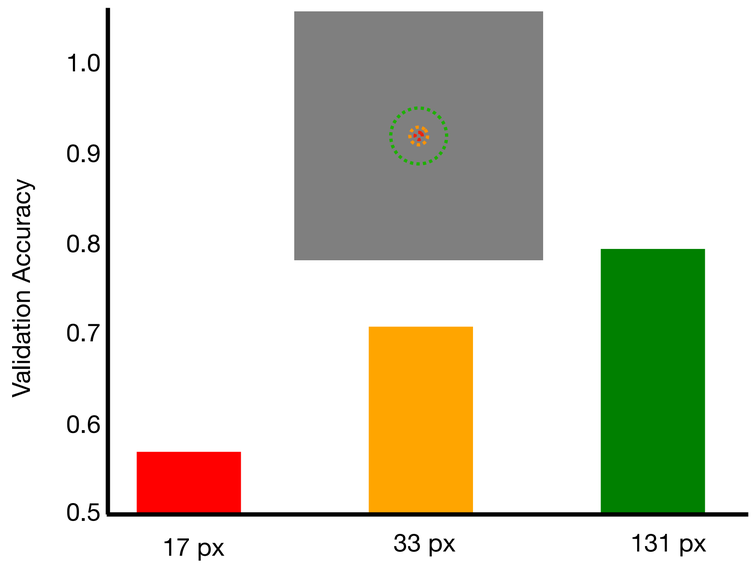
Using features from Alexnet layers to read-out the presence of extended contours, with fine-tuning (blue line) or not (orange line)



Visualizing gradients to determine whether full contour is being detected



Fine-tuning Bagnet models, which have the same depth (i.e. similar amount of non-linear transformations) but different and limited RFs

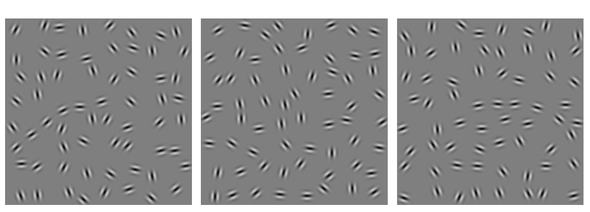


Accurate Contour Integration Requires Large Receptive Fields

Tuning to Relatively Straight Edges Shows Human Behavioral Signatures

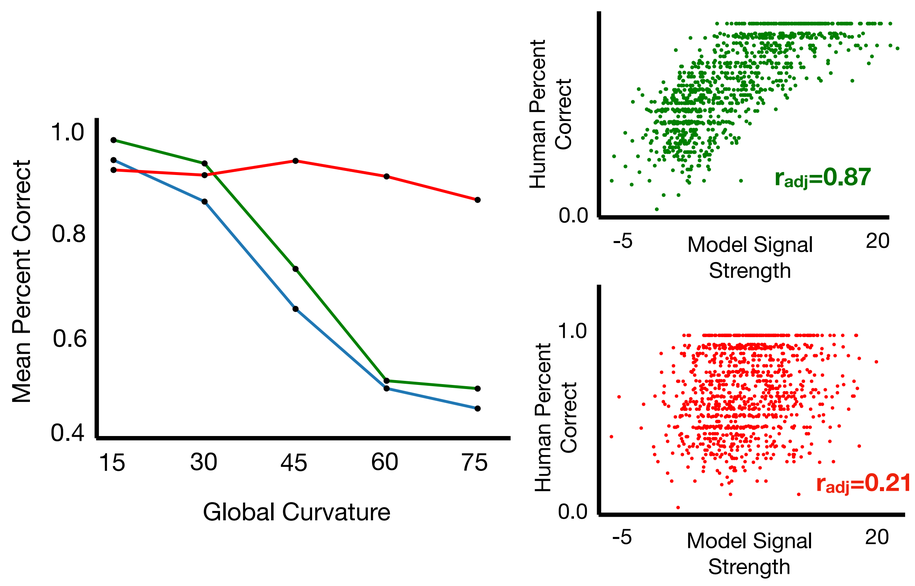
Varying Visual Diets

Relatively Straight Contours with Locally-aligned Elements



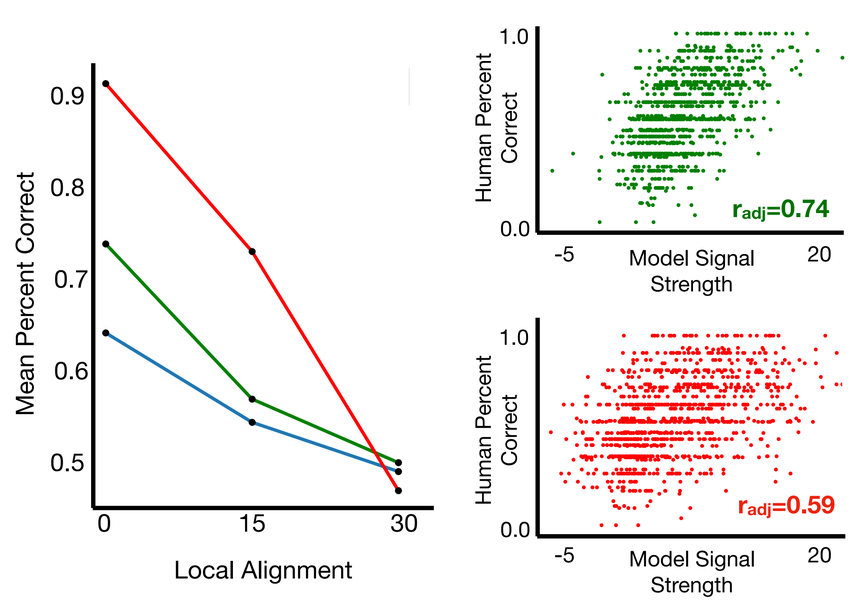
Broad Range of Contour Curvatures with Locally-aligned Elements

Sensitivity to Global Curvature

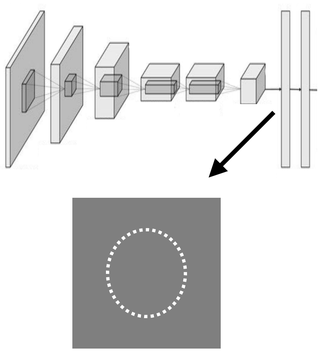


Model Tuned to Detect Relatively Straight Contours Showed More Human-like Sensitivity to Global Curvature

Sensitivity to Local Alignment



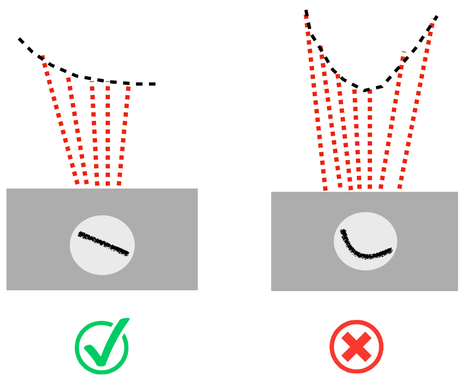
Model Tuned to Detect Relatively Straight Contours Showed More Human-like Sensitivity to Local Collinearity



SUMMARY

Purely feed-forward models, without horizontal-interactions or recurrence, can perform contour detection, but require large receptive fields to do so.

Human behavioral signatures (sensitivity to globlal curvature and local element alignment) arise when late-stage units are tuned to relatively straight contours.



QUESTIONS

What is the source of the straight edge bias? Natural image statistics? Interplay between early-stage association fields and later-stage integration units?