Final Report on Saliency Maps of Microstructures

Kessler DuPont

Background

At the end of my Arch Away semester, I was tasked with concluding my research by communicating the key takeaways of object saliency in the context of microstructures. This report will cover what saliency is and whether or not it should be pursued in the context of image-driven machine learning for microstructures. Please also see the associated informal presentation (.html / .pdf) that I gave to my research advisor, Dan Lewis.

Introduction

Understanding Microstructures

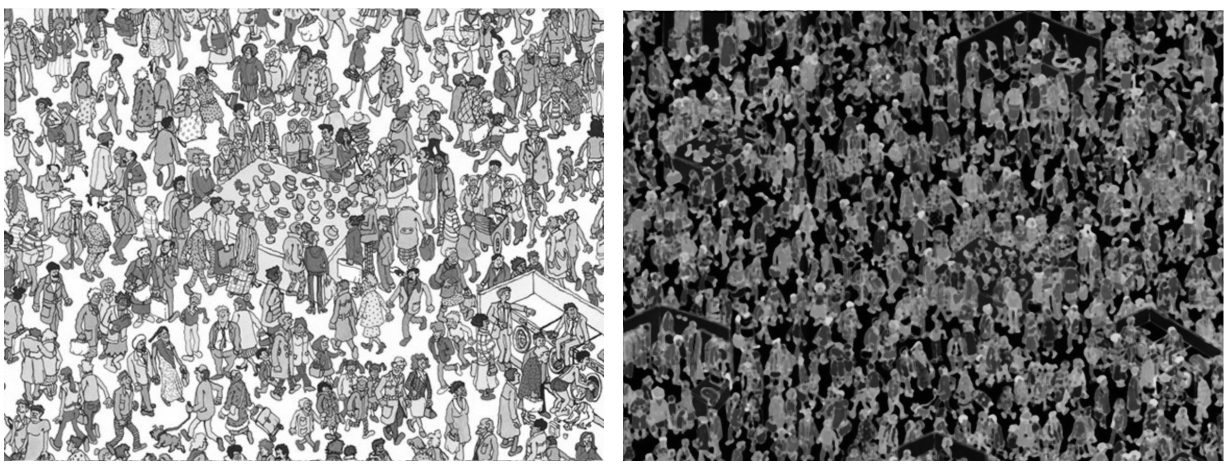
Looking at microstructures is an important way to understand the fundamental principles that determine strength, weight, ductility, piezoeletricity, and other critical characteristics of materials. Properties at the atomic scale aggregate in larger material samples and can indicate whether a material will be strong & lightweight, electricity conductive, and even whether it will be safe to use for a given application. Our modern society relies on understanding this truth. With this in mind, the IDML research group aims to use digital tools to further the understanding of material systems and reap the vast insights that will undoubtedly shape our future. This paper will focus on utilizing saliency algorithms to automate the task of digitally analyzing microstructure images.

What is Saliency?

Saliency in Humans

> *The definition of Salient Objects is an intrinsic property of the image, which can be reliably perceived among human subjects. [1]*

Humans use saliency to quickly identify interesting objects and patterns that appear in their field of view (fov). The most prominent or attention-grabbing object within the field of view can also be called the most salient object. When a human looks at an image, a salient object can be quickly separated from everything else in the field of view. This process is called foreground separation.



Humans intuitively look at important objects in an image and discard the background. The image on the left is from Where's Waldo [4], a children's puzzle book. In the image on the right, a computer algorithm highlights the important objects a human may be looking at while searching for Waldo.

The foreground can be separated from the background — everything else in the field of view — using a variety of different techniques that quantify how the salient object may vary in focus, contrast, color, position relative to the center of the fov, face-likeness, morphology, etc. In some cases, one object might exhibit similar or near-equal saliency with other objects; this means that none, one, two, or many salient objects may exist in a given fov.

Digital Saliency

Defining Digital Saliency

Digital saliency takes inspiration from human neuroscience and translates the human vision system into algorithms that rely on quantitative analysis of various image chararteristics.

Operating On Fundamental Image Characteristics

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Note: This section will feature papers referenced in [2].

Color

Color-based saliency algorithms utilize differences in color to determine salient regions of an image. These algorithms would be useful for locating features that are discernible by color. For example, these algorithms would excel at locating a red ball in green grass.

- Z. Jiang and L. S. Davis. Submodular salient region detection. In CVPR, pages 2043–2050, 2013
- R. Liu, J. Cao, G. Zhong, Z. Lin, S. Shan, and Z. Su. Adaptive partial differential equation learning for visual saliency detection. In CVPR, 2014.
- H. Peng, B. Li, R. Ji, W. Hu, W. Xiong, and C. Lang. Salient object detection via low-rank and structured sparse matrix decomposition. In AAAI, 2013.
- X. Shen and Y. Wu. A unified approach to salient object detection via low rank matrix recovery. In CVPR, 2012.

Contrast

Contrast-based algorithms use a difference in contrast to identify salient objects. For example, a contrast-based algorithm could be implemented to identify dark-colored cracks in microstructure images. Some implementations of this algorithm could rely on comparing contrast between differing regions (global contrast), while others could rely on g.

Local Contrast

Local contrast is computed by an algorithm that only considers one part of an image at a time. Several algorithms from [2] have been listed below:

- K. Shi, K. Wang, J. Lu, and L. Lin. Pisa: Pixelwise image saliency by aggregating complementary appearance contrast measures with spatial priors. In CVPR, pages 2115–2122, 2013.
- C. Scharfenberger, A. Wong, K. Fergani, J. S. Zelek, and D. A. Clausi. Statistical textural distinctiveness for salient region detection in natural images. In CVPR, pages 979– 986, 2013.
- R. Margolin, A. Tal, and L. Zelnik-Manor. What makes a patch distinct? In CVPR, pages 1139–1146, 2013.
- M.-M. Cheng, J. Warrell, W.-Y. Lin, S. Zheng, V. Vineet, and N. Crook. Efficient salient region detection with soft image abstraction. In ICCV, pages 1529–1536, 2013.
- H. Jiang, J. Wang, Z. Yuan, T. Liu, and N. Zheng. Automatic salient object segmentation based on context and shape prior. In BMVC, 2011.
- H. Yu, J. Li, Y. Tian, and T. Huang. Automatic interesting object extraction from images using complementary saliency maps. In ACM Multimedia, pages 891–894, 2010.
- R. Valenti, N. Sebe, and T. Gevers. Image saliency by isocentric curvedness and color. In ICCV, pages 2185–2192, 2009.

- R. Achanta, F. Estrada, P. Wils, and S. Susstrunk. Salient ¨ region detection and segmentation. In Comp. Vis. Sys. 2008.
- F. Liu and M. Gleicher. Region enhanced scale-invariant saliency detection. In ICME, pages 1477–1480, 2006.
- Y.-F. Ma and H.-J. Zhang. Contrast-based image attention analysis by using fuzzy growing. In ACM Multimedia, 2003.

Global Contrast

> *Saliency, defined as uniqueness in terms of global regional contrast... is introduced by measuring the global contrast between the target region with respect to all other image regions. [2]*

Unlike local contrast algorithms, global contrast algorithms use the entire image to quantify the saliency of each image subregion.

Governed by: $s(r_i) = \sum_{j=1}^{N} w_{ij} D_r(r_i, r_j)$, where r_i are image regions [2]

Several algorithms from 2 have been listed below:

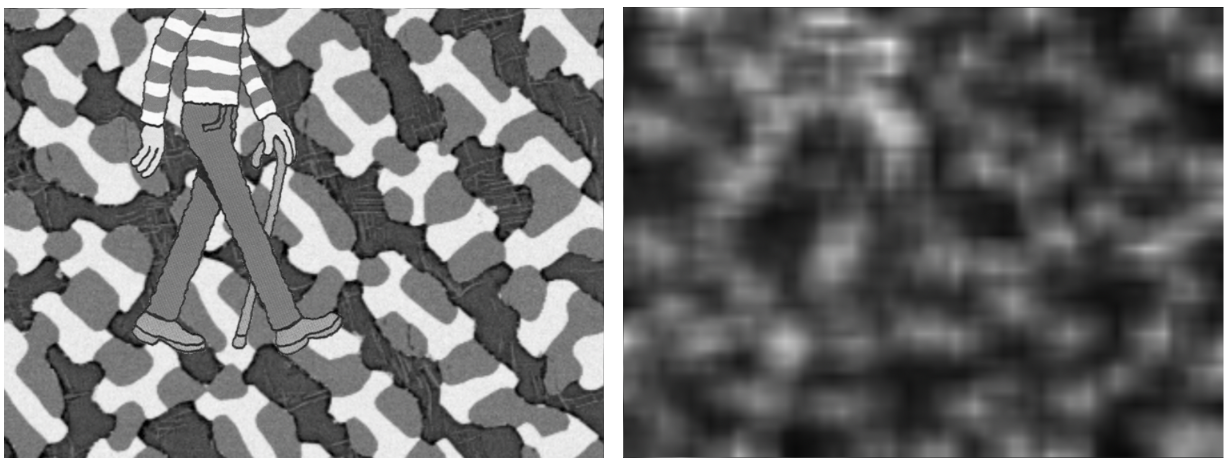
- Z. Jiang and L. S. Davis. Submodular salient region detection. In CVPR, pages 2043–2050, 2013
- P. Jiang, H. Ling, J. Yu, and J. Peng. Salient region detection by ufo: Uniqueness, focusness and objectness. In ICCV, 2013.
- Y. Jia and M. Han. Category-independent object-level saliency detection. In ICCV, 2013.
- Q. Yan, L. Xu, J. Shi, and J. Jia. Hierarchical saliency detection. In CVPR, pages 1155–1162, 2013.
- F. Perazzi, P. Krahenb ¨ uhl, Y. Pritch, and A. Hornung. ¨ Saliency filters: Contrast based filtering for salient region detection. In CVPR, pages 733–740. IEEE, 2012.
- M.-M. Cheng, N. J. Mitra, X. Huang, P. H. S. Torr, and

S.- M. Hu. Global contrast based salient region detection. IEEE TPAMI, 37(3):569–582, 2015.

- Y. Hu, D. Rajan, and L.-T. Chia. Robust subspace analysis for detecting visual attention regions in images. In ACM Multimedia, pages 716–724, 2005.

Morphology

Morphology-based saliency algorithms are the most promising due to their ability to identify proto-objects that are salient in shape. These algorithms could excel in situations where two different objects have similar contrast.



Contrast-based saliency algorithms can fail to differentiate two dfferent objects when the two objects have similar textures. The image on the left is a synthesized image from one of the microstructure images in [6]. The image on the right shows that the output from opencv-python's spectral residual contrast algorithm fails to highlight a single object.

One interesting method from [2] is listed below:

- P. Mehrani and O. Veksler. Saliency segmentation based on learning and graph cut refinement. In BMVC, pages 1–12, 2010.

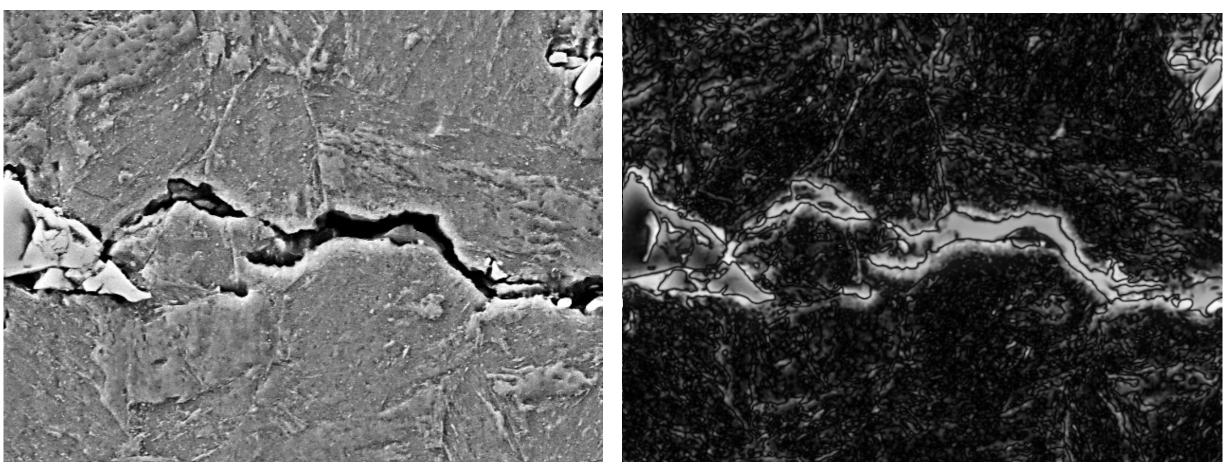
Focus

The mathematics used in focus-pior saliency algorithms could potentially be used to calibrate microscopes that are photographing difficult edges or faces of a material sample. Two algorithms from [2] have been listed because they may be of use in this regard:

- P. Jiang, H. Ling, J. Yu, and J. Peng. Salient region detection
- N. Li, J. Ye, Y. Ji, H. Ling, and J. Yu. Saliency detection on light fields. In CVPR, 2014.

At the Speed of Simplicity

While the human vision system remains far more intelligent and complex than any algorithm or deep learning network that exists, well-designed algorithms that rely on the fundamental image characteristics covered above can quickly scan large databases and generate saliency maps at scale. That is, an intrinsic salient map algorithm can scan through millions of images and provide needed insight with a quick turnaround on the order of milliseconds.



Saliency algorithms can highlight important objects like this crack in a niobium carbide HSLA steel. The image on the left is taken from [5]. The image on the right is the output from opencv-python's center surround fine-grained contrast algorithm.

I found that opencv-python takes about 2 milliseconds per image when running using python 3.8 on a 1st generation m1 Macbook Pro, while a trained human eye might take five times as long at best [3]. In a race between a human and a computer, the saliency algorithm's edge translates to hours of time saved in the best case, and in reality, a computer could likely operate a million times faster. Having the ability to rapidly locate, label, and quantify anomalies in materials starts with object saliency; that is, object saliency could open new doors in the world of material science.

Next Steps

Pursuing Morphology-Based Algorithms

While using a classifier that uses deep learning seems promising, benefits can be had by opting for a classical algorithm. Intuitively, morphology-based saliency algorithms are a promising alternative to using neural networks, so it is critical that these and other categories of classical algorithms are benchmarked in context.

Creating Saliency Maps with Neural Networks

Testing and validating a neural network can be cumbersome, but as deep learning technology ultimately progresses it will likely surpass traditional algorithms in domain-specific comprehension. Since current saliency algorithms strive to be a binary classification problem, neural networks could be built with multiple output neurons that highlight cracks, boundaries, etc. that are interesting.

Conclusion

Having the ability to rapidly locate, label, and quantify anomalies in materials starts with object saliency; that is, object saliency could open new doors in the world of material science. While opencv's contrast-based algorithms were shown to have weaknesses, there are still many other algorithms that need to be benchmarked in context and at scale.

Acknowledgements

I would like to thank Prof. Dan Lewis for inviting me to his research team and guiding me through the research process.

Code

Here is a simplified script to get started:

▼ Run this python 3.8 code to try out the opencv algorithm

```
import cv2
import numpy as np
import sys
# fine-grained center surround method
def centerSurround(i):
    fgMethod = cv2.saliency.StaticSaliencyFineGrained_create()
    (success,fgMap) = fgMethod.computeSaliency(i)
    return fgMap
# spectral residual method
def spectralResidual(i):
    spMethod = cv2.saliency.StaticSaliencySpectralResidual_create()
    (success,spMap) = spMethod.computeSaliency(i)
    return spMap
def generateSaliencyMap(i, mode='1'):
    # time the function
    t = centerSurround if mode == '1' else spectralResidual
    from datetime import datetime
    ta = datetime.now()
    m = t(i)
    tb = datetime.now()
    print('delta = {0}'.format(tb - ta))
    # convert the saliency map to a 0-255 scale for viewing
    m *= 255
    # threshold the map (binarize the image)
    _,m = cv2.threshold(m,127,255,cv2.THRESH_BINARY)
    # cast to uint8 for viewing
    m = m.astype(np.uint8)
    return m
if __name__ == "__main__":
    if len(sys.argv) < 3:
        print('usage: python get-saliency-map.py [mode: 1/2] [path:
relative path, no quotes]')
        exit()
    path = ''.join(sys.argv[2:])
    i = cv2.imread(path)
    m = generateSaliencyMap(i, sys.argv[1])
    cv2.imshow('saliency map',m)
    cv2.waitKey(0)
```

Bibliography

During my research, I skimmed through many papers. My bibliography is available as a .html or a .bib file.

References

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2. https://arxiv.org/pdf/1411.5878.pdf "Borji - Salient object detection: A survey. - doi 10.1007/s41095-019-0149-9"
3. https://news.mit.edu/2014/in-the-blink-of-an-eye-0116 "In the blink of an eye - MIT neuroscientists find the brain can identify images seen for as little as 13 milliseconds."
4. https://123sonography.com/blog/where-waldo-part-1 "Where is Waldo? Part 1 - 123 Sonography"
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