

Artificial Intelligence (AI) for Advanced Image Analysis - book review and discussion

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Abstract

Sreenivas (Sreeni) Bhattiprolu is the Head of digital solutions at Zeiss, and author of the ebook “AI for Advanced Image Analysis”. In this discussion, Sreeni, Viji and Binghao are exploring trends, challenges and opportunities in AI guided microscopy data analysis from the viewpoint of industry, research and clinical needs.

Biographies:



Sreenivas (Sreeni) Bhattiprolu, Head of digital solutions at Zeiss, a lifelong microscopist with a Ph.D. in Materials Sciences and extensive experience in applying microscopy in various fields, is also the author of the eBook titled ‘AI for Advanced Image Analysis’.



Viji Draviam, Professor of Cell and Molecular Biology, at the Queen Mary University of London exploits high-resolution live-cell microscopy and automated image analysis methods to understand how human cells maintain chromosome numbers.



Binghao Chai, postdoctoral computer vision scientist in the Draviam group with six years of expertise in developing DL tools and solutions for clinical pathology and frontiers cell biology.

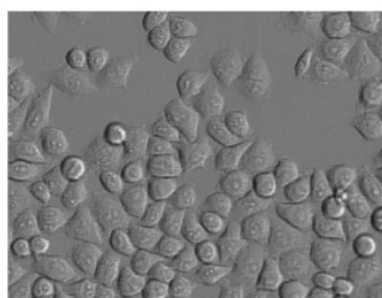
Viji: Hello Sreeni, it’s a pleasure to talk about your recent eBook “AI for Advanced Imaged Analysis”.

As you mentioned “AI is becoming an increasingly valuable tool for addressing challenges in life sciences research and beyond. While some people in the field are already leveraging this technology, many others find it intimidating.” What inspired you to bring out this eBook?

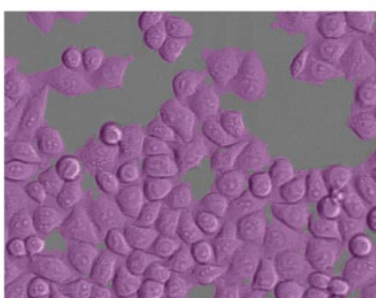
Sreeni: The inspiration behind creating this eBook

was to bridge the gap between the potential of AI in microscopy and the apprehension that many researchers have towards this technology. The eBook’s primary aim is to educate researchers from academia and industry about the profound benefits AI can bring to the field of microscopy.

In the eBook, we’ve focused on the fundamentals of both machine learning and deep learning, making a deliberate effort to demystify these algorithms. The goal is to provide researchers with a clear

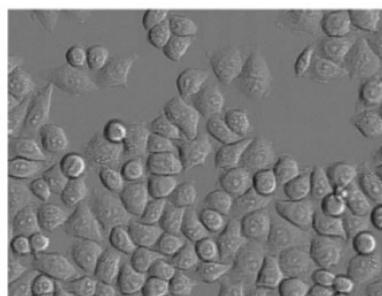


(a)



(b)

Figure 24: (a) Phase contrast image of HeLa cells captured at 10x magnification. (b) Semantic segmentation result using a U-Net-based Deep Learning architecture. The pink area represents the cellular region, which has been successfully segmented from the background. However, it should be noted that individual cells are not separated by this approach.



(a)



(b)

Figure 25: (a) Phase contrast image of HeLa cells captured at 10x magnification. (b) Result of instance segmentation using the Mask2Former Deep Learning method, clearly separating individual cells and enabling direct use of the result in applications such as cell tracking.

Image (above): Excerpt from the ebook "AI for advanced image analysis" showing two different types of image segmentation using different Deep Learning methods.

understanding of how and why AI works, avoiding the perception of it as a “black box.” For example, in the book, we explained the difference between semantic and instance segmentation, making it easier for researchers who might not be familiar with technical machine learning terms to understand these concepts (See figure above - an excerpt from the eBook).

The response to our initial release has been overwhelmingly positive, both from our internal colleagues at ZEISS and external readers. Given this, we are excited to announce that we’re in the process of developing a second version of the eBook. This upcoming edition will delve into additional aspects of AI in microscopy, such as denoising and image reconstruction, to further empower researchers in harnessing the potential of AI in their work.

Viji: We started building one of the first DL-guided Spindle analysis tool ‘SpinX’ four years ago (Dang 2023, JCB) - we recently reviewed a wide range of DL-guided in microscopy (Chai 2023., TiCB). It seems like AI is supporting a digital transformation

through automated image analysis. Do you think the microscopy field is going through a transformational change?

Sreeni: Almost every aspect of our life is currently undergoing a remarkable transformation, thanks to AI. Microscopy is no exception. Picture this: a microscope that’s no longer a passive observer but a dynamic partner in the image acquisition and analysis process. The microscope, guided by AI, can autonomously identify regions of interest, and configure the imaging experiment accordingly. But here’s where it gets truly exciting: as you watch, the microscope becomes an active explorer, starting with an overview and then seamlessly zooming in, all guided by the insights it gains from previous images. This is the era of “Smart Microscopy,” where it’s like having a skilled assistant by your side, helping you uncover hidden insights in real time rather than hours.

Viji: What are the emerging challenges in terms of Quality control to ensure high-quality AI-based image analysis tools?

Sreeni: Ensuring high-quality AI-based image analysis tools presents its own set of challenges.

One significant hurdle is the need for a robust and diverse dataset for training AI algorithms. Without representative data, AI tools may struggle to generalise and provide accurate results across various applications and samples.

Another challenge is the interpretability and explainability of AI-driven results. Users often need to understand why and how the AI arrived at a specific conclusion, especially in scientific research. Ensuring that AI can provide transparent insights is essential.

Next, the continuous adaptation and validation of AI models as microscopy techniques evolve can be demanding. These models must stay relevant and effective as new imaging technologies and sample types emerge.

The most significant challenge, in my opinion, is the absence of established industry standards for AI. Without such standards in place, research groups and organisations tend to create their own individualised best practices, tailored to their unique circumstances. This decentralised approach can result in a scenario where evaluating the quality of AI models becomes exceedingly complex.

Binghao: Computer Scientists are trying to answer the interpretability question by breaking the “black-box”. Although their methods cannot break the black-box completely, their studies are the “starting point” of interpreting deep learning methods. An example method here is called “activation maximisation”, and their computational paper is “Methods for interpreting and understanding deep neural networks” (Montavon et al., 2018)

Viji: Are there technical hurdles in terms of AI algorithms development?

Sreeni: Considering the rapid technological advancements in AI over the past two decades, my concerns about technical hurdles are relatively minimal. Instead, I’m more focused on challenges

like the lack of industry standards, as previously mentioned, and the potential legal and ethical issues.

Technical challenges may surface when attempting to create unified AI models that span various microscopy modalities such as LM, EM, and XRM. However, with adequate training data and continued development efforts, these challenges can be overcome. The dynamism of AI technology allows us to adapt and evolve, making technical obstacles less worrisome in comparison to standardisation and ethical considerations.

Viji: Any examples of successful implementation in Drug discovery?

Sreeni: Many AI-focused biotech startups are emerging, all sharing a common mission: to expedite drug discovery. For example, BenevolentAI, has created an AI platform that can analyse extensive biomedical data to identify new drug targets and design new drugs.

When it comes to microscopy, a major pharma company recently harnessed AI to analyse microscopy images of cell cultures. This approach significantly accelerated the drug discovery process by pinpointing compounds that influence specific cellular features relevant to diseases.

Also, tools like ZEISS’ arivis Cloud are democratising AI technology in microscopy. They make AI-driven image analysis accessible to researchers, streamlining this critical aspect of microscopy, and thereby enhancing the efficiency of drug discovery efforts.

Viji: Could you provide insights into the key skills and knowledge areas that professionals in the microscopy field should develop to effectively incorporate AI into their work?

Sreeni: In the early days of AI, about a decade ago, incorporating AI into microscopy required a deep understanding of coding and machine learning. Today, we no longer require coding skills thanks to no-code software like ZEISS’ arivis Cloud, the arivis Pro deep learning operator and the ZEN AI toolkit.

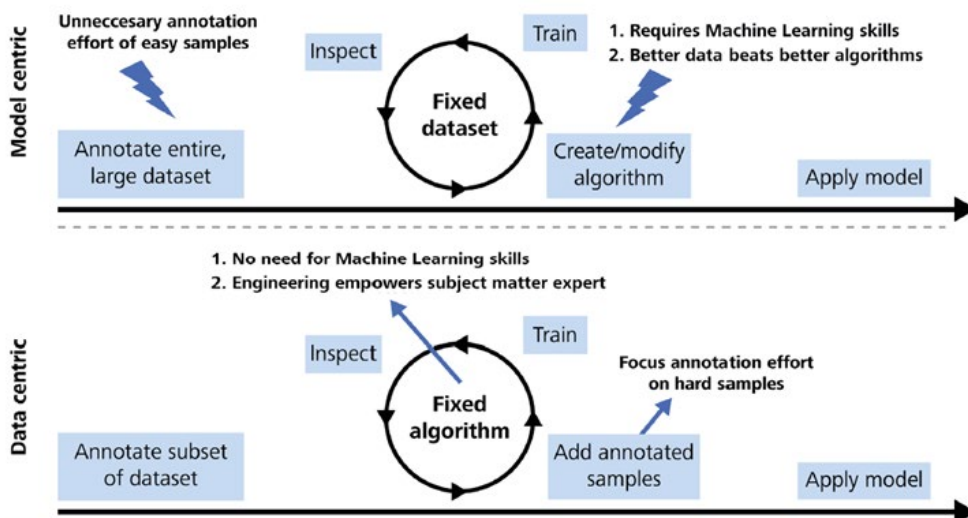


Figure 13: Model-centric versus data-centric model development for microscopy applications.

Image (above): Excerpt from the ebook 'AI for Advanced Image Analysis' illustrating two different types of model development for microscopy applications.

The key skills that microscopists should develop primarily involve understanding how to effectively use these AI tools to enhance their work. It's about integrating AI seamlessly into existing expertise, rather than acquiring new skills. These software tools are incredibly powerful and can streamline routine tasks, image analysis, and data interpretation.

When it comes to using AI in research, it's essential for researchers to be aware of the difference between model-centric and data-centric approaches. In the former, you work with a fixed dataset that requires complete annotation, and you test it with various machine learning algorithms, which demands a solid grasp of machine learning. A better approach is the 'Data-Centric' one, where the algorithm remains fixed, and the user, typically a subject matter expert, annotates only the necessary data to initiate model training. Additional annotations are added only in areas where the model struggles. This approach is often the most efficient way to utilise AI in research contexts. (See illustration above from eBook).

It is also important to note that while these software tools are versatile, they may not cover every aspect of research, especially in cutting-edge or novel areas of discovery. In such cases, having a basic knowledge of Python coding can be a valuable

asset. Python skills allow researchers to further customise and adapt these software tools to suit customised applications and experimental needs. This combination of domain expertise and adaptable coding skills can be a potent force in pushing the boundaries of research in the microscopy field.

Viji: How can we build reusable AI models? Open-source frameworks, libraries and DL models will be excellent for further research and deployment. Do you have a practical guide?

Sreeni: Making AI models reusable and sustainable in scientific image datasets is indeed challenging. The variability in microscopy datasets makes it hard to use the same AI model in different situations. To address this, it's important to make AI accessible to a broader range of researchers so they can contribute to developing more generalised models that can be reused.

Sharing training data with annotations is vital, although regrettably, it's not widespread, even in academic circles.

Platforms like arivis create models in an interoperable format, allowing for further customisation for specific niche tasks. Dockerising AI models is another practical method for

enhancing sustainability and efficiency, as it allows for reproducibility across various systems.

Quality matters a lot. Good data is essential for dependable results. Think of it like the strict checks that smartphone apps go through before they're released.

In summary, a combination of accessibility, data sharing, format interoperability, Dockerisation, and quality assurance processes is essential to promote the reusability and sustainability of AI models in scientific image analysis.

Viji: Where do you foresee ML (machine learning) engineers to be vitally important in the microscopy field?

Sreeni: ML engineers are really helpful in microscopy and research. Instead of spending time and resources reinventing algorithms already available to researchers, like those on platforms such as arivis, ML engineers can help automate insights from specialized experiments. These experiments often push the boundaries of our understanding, and ML engineers, working with researchers, can make the data more valuable and speed up scientific discovery.

Viji: What are your thoughts about AI algorithms for tracking objects live?

Sreeni: AI-based object-tracking algorithms do exist. I haven't explored them extensively because traditional algorithms work quite well for tracking objects. Traditional methods are reliable, and they offer transparency, unlike deep learning, which can sometimes be a bit like a black box. While traditional algorithms might be slower, it's worth noting that many microscopy tracking experiments don't necessarily demand real-time results. However, if a specific application requires real-time tracking, that's when deep learning methods become a valuable option.

Binghao: Unlike annotating objects in daily life, image annotation requires highly trained life sciences /clinical sciences experts – this is time-

consuming and expensive. What can we do as computer scientists to make the annotation easier, and are there any techniques for solid ground truth?

Sreeni: You're absolutely right; annotating scientific images often demands highly trained experts in life sciences or clinical sciences. Their expertise is valuable, and it wouldn't be practical to burden them with manually annotating every pixel in every image. Fortunately, there are algorithms, like the ones available on platforms such as arivis, that can work with partial labels, which can save time and resources.

Meta recently introduced a "segment anything" model that actively learns from user annotations in real-time, automatically adding additional annotations (Kirrilov et al., 2023). To streamline the annotation process and accelerate the development of training data, integrating such algorithms into annotation pipelines is a promising approach. This way, computer scientists can contribute to making image annotation more efficient and accessible.

Binghao: Given the black-box nature of DL, how can users be certain of the strength of a model.

Sreeni: To ensure the reliability of deep learning (DL) models, it's essential to have a ground truth for testing AI models. This means involving experts in the evaluation process.

It's important to understand that being a biology or geology expert doesn't automatically make someone an image analysis expert. These researchers require proper training in the fundamentals of image analysis, not only in using AI. Fortunately, many universities are now offering image analysis courses, and I'm optimistic that the next generation of researchers will be more proficient in image processing, which will help identify and rectify any errors made by AI.

Binghao: This last question is relevant to clinical experts. AI model without descriptors cannot get FDA approval – what's the trend here?

Sreeni: I'm not an FDA approval expert, but I can share that there's a notable trend toward



modernising the approval process. For instance, the recent FDA Modernisation Act 2.0 introduced alternatives to animal trials, such as cell-based assays with organoids and organ-on-a-chip models, as well as digital twins. These multidimensional

datasets require AI for efficient data analysis. This indicates that the FDA is likely developing or has already defined a framework for incorporating AI components into the approval process.

The eBook, 'AI for Advanced Image Analysis' is available to download for free here: <https://www.arivis.com/ai-ebook>

References

- 1) Dang et al., 2023 <https://doi.org/10.1083/jcb.202111094>
- 2) Chai et al., 2023 <https://doi.org/10.1016/j.tcb.2023.10.010>
- 3) Montavon et al., 2018 <https://doi.org/10.1016/j.dsp.2017.10.011>
- 4) Kirrilov et al., 2023 <https://arxiv.org/abs/2304.02643>

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