UNIVERSITY OF TARTU
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Stacks of Gold: Utilizing GANs to Enhance 3D Microscopy Imaging Data

Master's Thesis (30 ECTS)

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Abstract:
Confocal microscopy, a pivotal tool in biomedical research, offers detailed visualizations of living cells, providing insights into their spatial morphology, interactions, and life cycle progression. However, capturing and analyzing these images involve significant trade-offs. Transmitted-light (TL) microscopy, while non-invasive and relatively straightforward, yields low-contrast images of suboptimal quality, which are hard to analyze. Conversely, fluorescence (FL) microscopy delivers superior image quality but is expensive, time-consuming, and potentially harmful to cells. This thesis explores the potential of Generative Adversarial Networks (GANs) to address these challenges. We focus on extracting detailed 3D information from TL, specifically bright-field (BF) images, and enhancing the quality of 3D FL microscopy images through deconvolution, denoising, and deblurring. We present several successful GAN applications across diverse datasets, revealing the potential for *in silico* extraction of accurate 3D information from BF images, which was previously considered unattainable, and high-quality signal recovery from optically distorted 3D FL images. One case study demonstrates the downstream application of our *in silico* enhanced FL images to improve 3D reconstruction from BF. These findings could expedite the biomedical imaging workflow by reducing time expenditure and enabling novel imaging experiments, such as the non-invasive study of volumetric cell morphology.

Keywords: deep learning, generative adversarial networks, convolutional neural networks, confocal microscopy, image-to-image translation, bright-field microscopy, fluorescence microscopy.

CERCS: T111 — Imaging, image processing; P176 — Artificial intelligence; B110 — Bioinformatics, medical informatics, biomathematics, biometrics.

Kullakuhilad: 3D-mikroskoopia pildikvaliteedi parandamine GAN-idega

Lühikokkuvõte:

Konfokaalmikroskoopia, mis on biomeditsiiniuuringute tähtis vahend, võimaldab elusate rakkude üksikasjalikku visualiseerimist, andes ülevaate nende ruumilisest morfoloogiast, vastastikmõjudest ja elutsükli kulgemisest. Nende piltide jäädvustamine ja analüüsimine hõlmab siiski märkimisväärseid kompromisse. Läbiva valgusega mikroskoopia (TL) on küll mitteinvasiivne ja suhteliselt lihtne, kuid annab madala kontrastsusega ja ebaoptimaalse kvaliteediga pilte, mida on raske analüüsida. Seevastu fluorestsentsmikroskoopia (FL) annab parema pildikvaliteedi, kuid on kallis, aeganõudev ja potentsiaalselt rakke kahjustav. Käesolevas väitekirjas uuritakse generatiivsete vastandvõrkude (GAN) potentsiaali selliste probleemide lahendamisel. Me keskendume üksikasjaliku 3D-teabe eraldamisele TL, täpsemalt heledavälja (BF) piltidelt ja 3D FL-mikroskoopiapiltide kvaliteedi parandamisele dekonvolutsiooni, müra ja hägu eemaldamise abil. Esitame mitmeid edukaid GANi rakendusi erinevates andmekogumites, mis näitavad potentsiaali täpse 3D-teabe *in silico* ekstraheerimiseks BF-piltidest, mida varem peeti kättesaamatuks, ja kvaliteetset signaali taastamist optiliselt moonutatud 3D FL-piltidest. Üks juhtumiuuring näitab meie *in silico* täiustatud FL-kujutiste edasist kohaldamist, et parandada 3D rekonstrueerimist BF-ist. Need tulemused võivad kiirendada biomeditsiinilise pildistamise töövoogu, vähendades ajakulu ja võimaldades uudseid pildistamiskatseid, nagu näiteks rakkude mahulise morfoloogia mitteinvasiivne uurimine.

Võtmesõnad: Süvaõpe, generatiivsed vastandvõrgud, konvolutsioonilised närvivõrgud,konfokaalne mikroskoopia, pilt-pildiks translatsioon, helevälja mikroskoopia, fluorestsentsmikroskoopia.

CERCS: T111 — Pilditehnika; P176 — Tehisintellekt ; B110 — Bioinformaatika, meditsiiniinformaatika, biomatemaatika, biomeetrika .

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