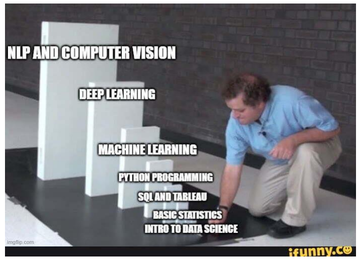
Pengantar

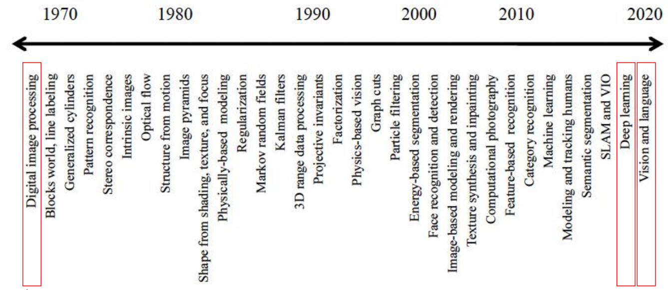
Ghandy, M.Sc.
IBDA4311 – *Computer Vision*

Computer Vision



hit the button

Computer Vision



Capaian Pembelajaran

- Silabus
- Instalasi
- Visi

Silabus

God's People for God's Glory

Silabus


Fakultas Sains dan Teknik
Course Syllabus
Semester Ganjil 2023/2024

Mata Kuliah	:	Computer Vision
Kode Mata Kuliah	:	IBDA4311
Bobot SKS	:	3

Logistik

- Jam kuliah : Selasa (09.00 – 12.00 WIB, 3x50 menit)
- Tempat : Lab Komputer 1 (Fisik)
- Harap menggunakan laptop ketika menghadiri kelas
- *Office hours* : by appointment
- E-mail : ghandy.salim@calvin.ac.id
- Komunikasi : Canvas (silabus, materi kuliah, tugas, *announcement*) maupun e-mail

Pustaka

Wajib

- [1] R. Szeliski, *Computer vision: algorithms and applications.* 2nd ed, London ; New York: Springer, 2022. https://szeliski.org/Book/

Rekomendasi

- [2] Stephen-Palmer, *Vision Science: Photons to Phenomenology*. MIT Press, 1999.
- [3] I. Goodfellow, Y. Bengio, and A. Courville, Deep learning., Cambridge, Massachusetts: The MIT Press, 2016. deeplearningbook.org/

Tips untuk berhasil dalam MK ini

- Konsisten mengerjakan tugas dan proyek sebaik mungkin.
- Bertanya dan partisipasi secara aktif di dalam kelas, sehingga dosen juga mendapat *feedback* jika terlalu cepat atau ada yang kurang jelas.
- Tidak tertinggal pelajaran: jika tidak paham di awal, segera menghubungi dosen atau bertanya kepada mahasiswa lainnya.
- Gunakan *office hours* dosen untuk lebih memahami materi dan tugas.
- Mata kuliah ini banyak memakai pemrograman dengan Python dengan *libraries* seperti numPy, scikit-learn, pandas, keras, pytorch, tensorflow. Bacalah dokumentasi dari *libraries* untuk lebih terbiasa menggunakannya. Anda juga dapat menggunakan ChatGPT untuk memahami kode-kode pemrograman yang diberikan

Setelah Anda menyelesaikan perkuliahan ini, Anda akan:

- Memahami dasar matematis, fisika, filosofis, dan teoretis yang digunakan di dalam *computer vision*
- Mampu membuat model *computer vision* untuk menyelesaikan berbagai macam permasalahan

Instalasi

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Anaconda

- Anaconda adalah sistem manajemen paket python
- Melalui Anaconda, maka versi dari paket python yang ada akan dikelola oleh package management system conda.

ANACONDA

Instalasi Anaconda

Gunakan tutorial di bawah ini untuk instalasi Anaconda:

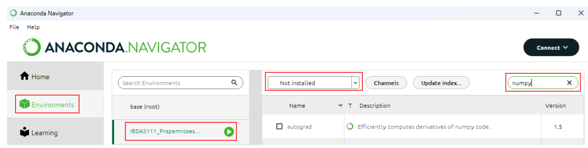
1. https://www.youtube.com/watch?v=itVBw_rNYjI&t=315s&ab_channel=GeekyScript

Gunakan tutorial di bawah ini untuk membuat "*new environment*" pada Anaconda (Gunakan Python 3.9.17 untuk mata kuliah ini):

1. https://www.youtube.com/watch?v=sv0ca-6liM8&ab_channel=LigentTutorials
2. https://www.youtube.com/watch?v=A8dlq-AUDpc&ab_channel=TheEducationMachine

ANACONDA

Paket Python



Instalasi *library* berikut ini pada *environment* baru anda:

1. numpy
2. scipy
3. matplotlib
4. seaborn
5. pandas
6. scikit-learn
7. tensorflow
8. keras
9. pytorch
10. jupyterLab
11. statsmodels
12. gensim
13. nltk

GPU cloud

- CIT (hanya untuk riset)
- GCP, AWS (mahal)
- Azure (free $200)
- Google colabs (gratis dengan limit)
- Gradient (gratis dengan limit): https://gradient.run/free-gpu
- Deepnote (gratis dengan limit): https://deepnote.com/

Perbandingan CPU dan GPU:
https://colab.research.google.com/notebooks/gpu.ipynb

Visi

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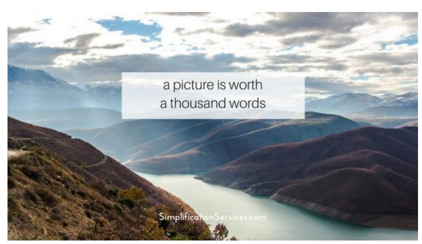
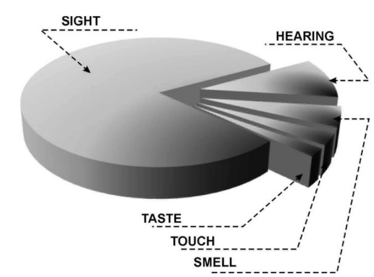
Apa itu visi?

- "A picture is worth a thousand words"

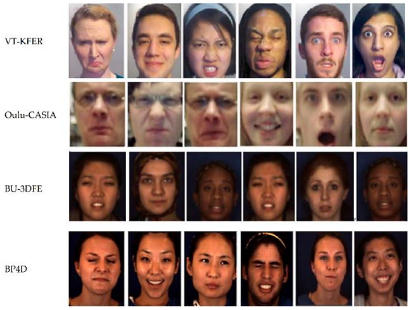


- Visi menentukan aksi

Human Sensory



Emotion Detection Based on Images



https://images.app.goo.gl/arDkySuQ5iXMgDLU8

Persepsi Visual

- Pemodelan lingkungan

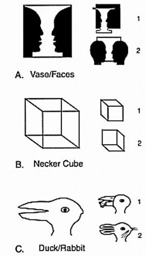


Figure 1.1.5
C. Duck/Rabbit
Ambiguous figures. Figure A can be seen either as a white vase against a black background or as a pair of black faces against a white background. Figure B can be seen as a cube viewed from above or below. Figure C can be seen as a duck (facing left) or a rabbit (facing right).

Persepsi Visual

- Pemodelan lingkungan

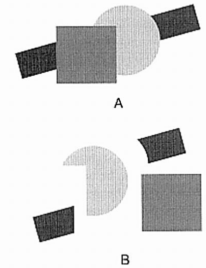


Figure 1.1.6
Visual completion behind partly occluding objects. Figure A is perceived as consisting of a square, a circle, and a rectangle even though the only visible regions are those shown separated in Figure B.

Persepsi Visual

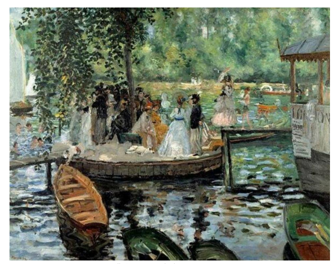
- Konstruksi Makna

Figure 1.1.9
Many kinds of dogs. Visual perception goes beyond the physical description of objects to classify them into known categories. Despite the substantial physical differences in their appearance, all these animals are readily perceived as belonging to the category of dogs.

Limitasi visi

- Lukisan impressionist berusaha memvisualkan aspek yang melampaui batasan visual

https://images.app.goo.gl/NYdj3zQMQHpyst9SA



https://perfectpicturelights.com/blog/impressionism-light-and-shadow

Limitasi visi

- Lukisan impressionist berusaha memvisualkan aspek yang melampaui batasan visual

Ilusi Optik

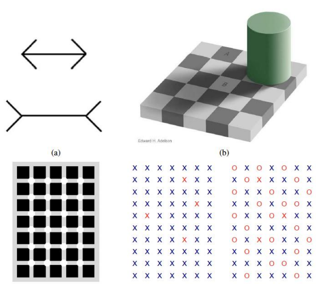
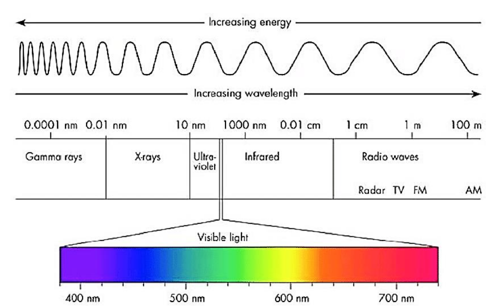


Figure 1.3 Some common optical illusions and what they might tell us about the visual system: (a) The classic Müller-Lyer illusion, where the lengths of the two horizontal lines appear different, probably due to the imagined perspective effects. (b) The "white" square B in the shadow and the "black" square A in the light actually have the same absolute intensity value. The percept is due to *brightness constancy*, the visual system's attempt to discount illumination when interpreting colors. Image courtesy of Ted Adelson, http://persci.mit.edu/gallery/checkershadow. (c) A variation of the Hermann grid illusion, courtesy of Hany Farid. As you move your eyes over the figure, gray spots appear at the intersections. (d) Count the red *X*s in the left half of the figure. Now count them in the right half. Is it significantly harder? The explanation has to do with a *pop-out* effect (Treisman 1985), which tells us about the operations of parallel perception and integration pathways in the brain.

Informasi Optikal

- Persepsi visual tergantung pada 3 hal:
  - Cahaya
  - Objek yang memantulkan cahaya
  - Sistem visual pengamat

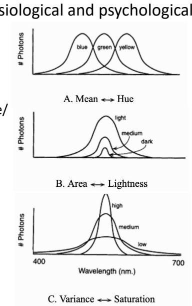
Spektrum Cahaya

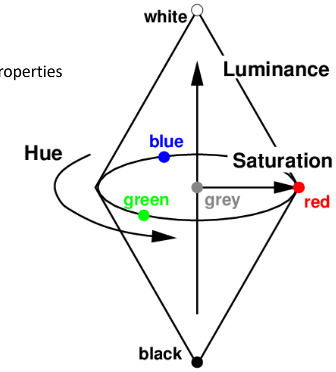


Istirahat 15 Menit

Color

- Color as physiological and psychological properties
  - Hue
  - Luminance/ Lightness/
  - Saturation

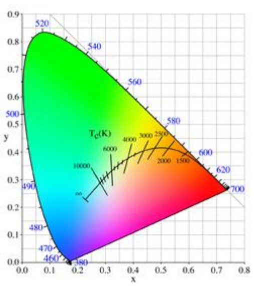




https://www.youtube.com/watch?v=T8kgnLT4goA&ab_channel=PhotoFeaver

Color Space

- Color space dibentuk dari kombinasi hue dan saturation

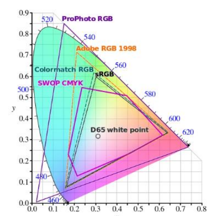


Color Space

Apa itu *Color Space*?

Warna adalah bagian integral dari sistem visi komputer. Color Space adalah kombinasi warna secara terorganisir dan terutama digunakan saat kita mereproduksi warna dalam media yang berbeda. Misalnya, Anda memiliki layar laptop dan monitor besar 52". Tentunya, akan ada perbedaan total piksel dan kombinasi warna. Ruang warna yang berbeda membantu membuatnya kompatibel dengan resolusi layar untuk memberikan pengalaman kombinasi warna yang lebih baik.

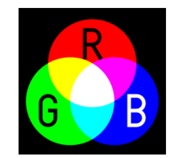
Diagram kromatisitas di samping ini mewakili Color Space. Ini menunjukkan segmen gelombang untuk nilai sumbu x dan y yang berbeda dengan berbagai panjang gelombang. Ruang membuat semua kemungkinan kombinasi warna terlihat oleh sistem penglihatan manusia. Ada banyak ruang warna seperti RGB, sRGB, dll. Kombinasi warna di bawah setiap ruang warna (ditandai dengan segitiga) menyimpan warna yang ditentukan.



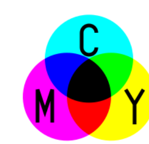
CIE 1931 xy chromaticity diagram (Under Wikimedia Commons free license CC BY-SA 3.0)

Color Space

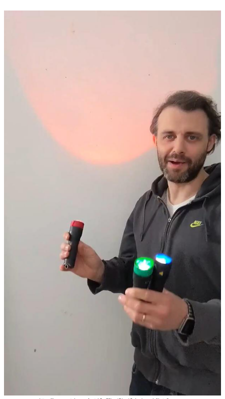
- Color addition vs substraction
- Cara mudah untuk mengingat perbedaan pencampuran warna aditif dan subtraktif adalah pencampuran warna aditif terjadi ketika kita mencampur lampu dengan warna berbeda sedangkan pencampuran warna subtraktif terjadi ketika kita mencampur cat atau bahan berwarna lainnya.



Color Addition



Color Substraction



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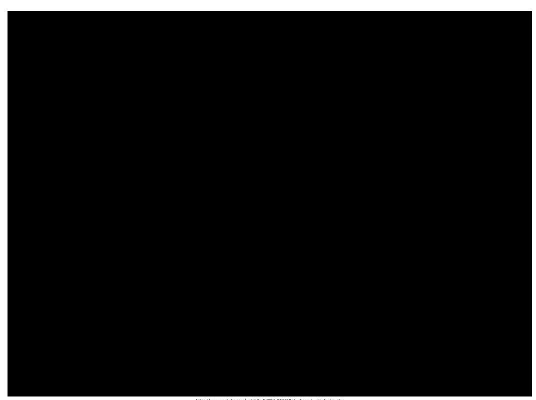
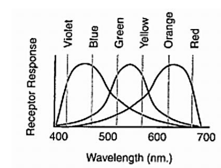


https://www.youtube.com/watch?v=Er7CM_RNFZ4&ab_channel=uclaphysicsvideo

Trichromatic Theory

- Young-Hemholtz: Teori trikromatik penglihatan warna adalah teori yang menyatakan ada tiga reseptor warna yang berbeda di retina. Sel kerucut di retina inilah yang memberi penglihatan warna. Teori ini mengatakan sel kerucut sensitif terhadap tiga warna berbeda: hijau, biru, dan merah



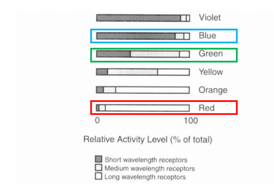


Figure 3.2.8
Patterns of activation in trichromatic theory.
Different color perceptions were proposed to result from different balances of activity in the three receptor systems, as illustrated here for six basic colors.

Trichromatic Theory

https://www.youtube.com/watch?v=l8_fZPHasdo&t=1s&ab_channel=TED-Ed

Opponent Process Theory

- Ewald Hering
- Warna komplementer: 2 warna bersebrangan, jika digabung akan saling cancel (hue)

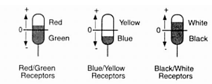
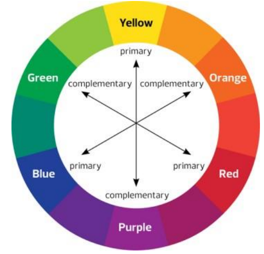


Figure 3.2.10
Hering's opponent process theory of color vision. Hering suggested that three types of receptors could respond in two opposite directions (+ versus -) from a neutral point (0) to signal red versus green, blue versus yellow, and black versus white.

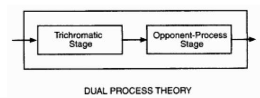


Opponent Process Theory

https://www.youtube.com/watch?v=NlrQsDd0bLQ&ab_channel=ParkerBourassa

Aplikasi warna komplementer

Dual Process Theory



- Hurvich & Jameson

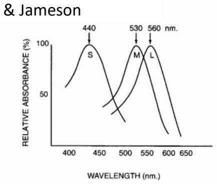
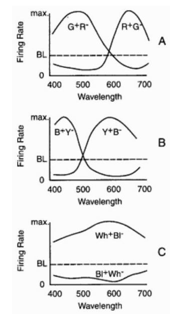
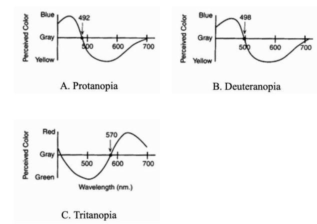


Figure 3.2.13
Neural response curves for the three types of cones. Short- (S), medium- (M), and long- (L) wavelength cones provide overlapping but differential responses to light of different wavelengths, as predicted by trichromatic theory. These curves are defined by the absorption spectra of the three pigments found in normal cones. (After Schnapf, Kraft, & Baylor, 1987.)



Buta warna

- Protanopia are unable to perceive any 'red' light
- Deuteranopia are unable to perceive 'green' light
- Tritanopia are unable to perceive 'blue' light.



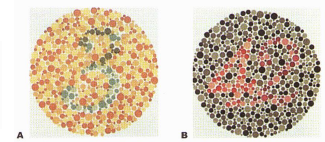


Plate 3.5
A test for color blindness. People with normal color vision see the number 3 in A and 42 in B, whereas protanopes see no number in A and a 2 in B, and deuteranopes see no number in A and a 4 in B.
(Courtesy of Graham-Field Surgical Company.)

Lintasan cahaya

- Cahaya menempuh lintasan terpendek (geodesik)

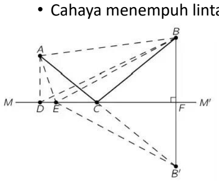
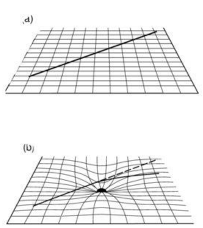
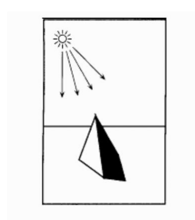


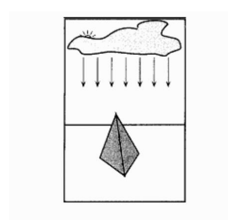
Illustration of the principle of least time.
We construct on the other side of MM' an artificial point B', which is the same distance below the plane MM' as the point B is above the plane.
Then we draw the line EB'.
http://www.feynmanlectures.caltech.edu/I_26.html



Iluminasi



A. Point-Source Illumination



B. Spatially Extended Illumination

Interaksi dengan permukaan objek

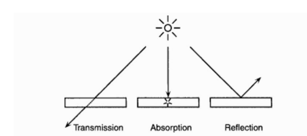


Figure 1.2.2
Interactions between light and surfaces. A photon can be transmitted through a surface, absorbed by it, or reflected off it.

Figure 1.2.3
Refraction of light. When light is transmitted through an object, it can be bent (refracted), leading to erroneous perceptions, such as the misaligned appearance of the spoon handle in this glass of water.

Mata

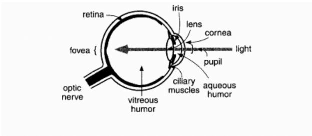
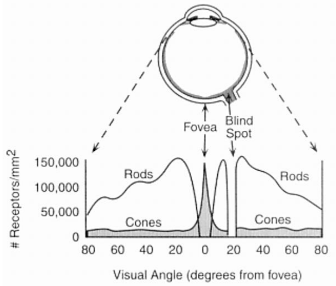


Figure 1.3.4
A cross section of the human eye. Light enters the eye through the cornea, aqueous humor, lens, and vitreous humor before striking the light-sensitive receptors of the retina, where light is converted into electrochemical signals that are carried to the brain via the optic nerve.



Sistem syaraf

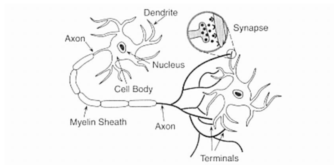
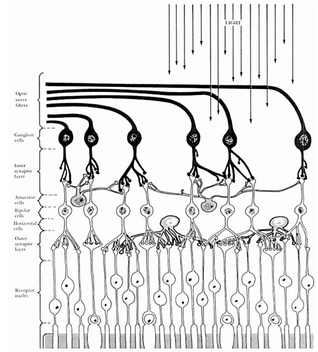


Figure 1.3.6
A typical neuron. A neuron is a cell that consists of a cell body that integrates graded electrical signals from its dendrites and transmits the result via discrete action potentials. These spikes travel along an axon, which is encased in a myelinated sheath, to terminals, where neurotransmitters are released at synapses to stimulate the dendrites of other neurons.



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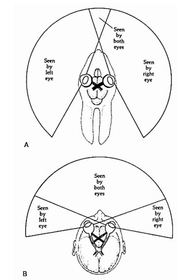
Sistem visual manusia



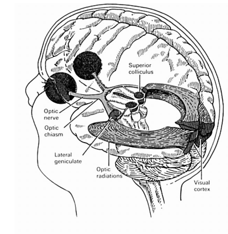


Figure 1.3.1
The human visual system. Visual processing begins in the eyes and is relayed to the brain by the optic nerve. The primary visual pathway then goes from the lateral geniculate nucleus to occipital cortex via the optic radiations. From there, visual information travels to other parts of the brain. A secondary pathway goes from the optic nerve to the superior colliculus and then to other brain centers. (From Rosenzweig & Leiman, 1982.)

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Classical Theory of Vision

THEORY	NATIVISM vs. EMPIRICISM	ATOMISM vs. HOLISM	ORGANISM vs. ENVIRONMENT
Structural-ism	Empiricism	Atomism	Organism
Gestaltism	Nativism	Holism	Organism
Ecological Optics	Nativism	Holism	Environment

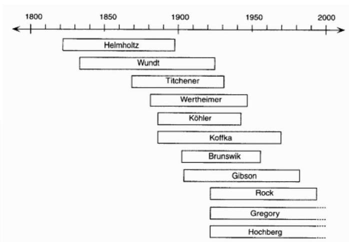

Figure 2.1.1
A timeline of visual theorists. The life spans of some of the most important psychological theorists of vision are represented over the past two centuries. Wundt and Titchener were structuralists; Wertheimer, Köhler, and Koffka were Gestaltists; Brunswick and Gibson were ecologists; and Helmholtz, Rock, Gregory, and Hochberg were constructivists.

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German Idealism

- Immanuel Kant: Phenomena, Noumena
- Gestaltism/holism: Wertheimer
  - The whole is different from the sum of its parts

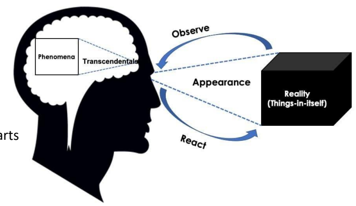

Figure 2.1.5
Emergent properties of a configuration. The arrangement of several dots in a line gives rise to emergent properties, such as length, orientation, and curvature, that are different from the properties of the dots that compose it.

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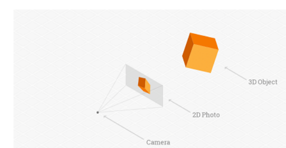
Phenomenology

- Edmund Husserl: Natural Experience
- Ecological Optics: James Gibson
  - "Ask not what's inside your head, but what your head's inside of"
  - foreshadow modern work in computational vision
- Constructivism: Helmholtz
  - global percepts are constructed from local information



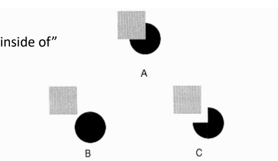


Figure 2.1.12
Two possible interpretations of a simple image. Image A can be interpreted either as a circle behind a square (interpretation B) or as a three-quarter circle next to a square (interpretation C). The fact that the visual system strongly prefers interpretation B to C can be explained by the principles of likelihood and/or Prägnanz.

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Reformational Philosophy

- Realita diciptakan dalam keragaman aspek → setiap aspek ciptaan bukan Pencipta
- Pre-theoretical vs theoretical thought:
  - Pre-theoretical thinking takes in reality as a whole
  - Theoretical thinking analyses reality from one aspect.
- Example:
  - a gardener may look at a plant in its unity as a plant; whereas a biologist may analyse the plant in terms of its biotic aspect.
  - When we see a sunset, we admire it as a sunset rather than in terms of the movement of the earth on its axis and its movement around the sun.

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Summary

- Silabus
- Instalasi
- Visi: fondasi dan filsafat

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Tuhan Memberkati

God's People for God's Glory
CALVIN INSTITUTE OF TECHNOLOGY

Pemrosesan Gambar

Ghandy, M.Sc.

IBDA4311 – *Computer Vision*

Capaian Pembelajaran

- Pengantar Paket Python
    1. Numpy
    2. PyTorch
    3. Matplotlib
    4. Opencv
- Pemrosesan Gambar
    - Membaca gambar
    - Channel dan format
    - Operasi dasar
    - Menulis Gambar
    - Video
    - Thresholding
    - Blurring

Pengantar Paket Python

Python

- Python adalah Bahasa pemrogrammang yang sifatnya high-level
- Python code hampir seperti pseudocode (bisa mengeskpresikan ide dengan bebas)
- Python yang akan digunakan adalah python 3.9

NumPy

- NumPy adalah paket untuk melakukan perhitungan numerik (vs Scipy lebih untuk matematika sains)
- Array berbentuk objek
- Sangat berguna untuk problem linear algebra

Array and Matrices

- Array di numpy (np.array) merupakan kumpulan daftar elemen
- Setiap array harus memiliki tipe yang sama
- Beberapa datatype:
    - Float (float16, float32, float64)
    - Int (int8, int16, int32, int64)
    - Uint
    - Bool
    - Complex
- Matrices adalah array yang memiliki 2 jenis dimensi
- Jika memiliki lebih dari 2 jenis dimensi disebut Tensor

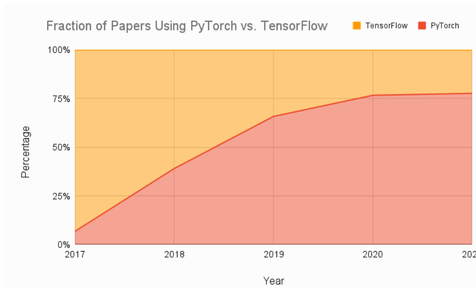
Operasi Matriks

- Keunggulan numpy terletak pada operasi matriks
- Operasi matematika dasar (+,-,/,*,%) dianggap sebagai operasi elemen
- Operasi matriks yang umum dapat menggunakan:
    - Matrix multiplication: np.matmul
    - Transpose: property objek numpy .T
    - Inverse: np.linalg.inv
    - Penjumlahan sepanjang axis: np.sum
    - Menumpuk 2 array: np.stack
    - Menyambung 2 array: np.concatenate

PyTorch

- PyTorch adalah paket untuk deeplearning dan optimisasi operasi tensor
- Mengapa numpy dan opencv tidak cukup?
    - Karena PyTorch dapat menggunakan GPU untuk operasi tensor
    - Karena PyTorch dapat melakukan turunan parsial otomatis
- Ada beberapa deep learning frameworks yang populer:
    - TensorFlow (google)→ compatible dengan KERAS (banyak digunakan di industri)
    - PyTorch (facebook)→ lebih mudah untuk mengutak-atik tensornya (banyak digunakan untuk riset)

PyTorch vs TensorFlow



Matplotlib

- Matplotlib adalah paket untuk menghasilkan grafik dengan fleksibel
- Terdapat beberapa toolkit tambahan yang bisa dibangun diatas matplotlib:
  - Basemap dan cartopy: untuk proyeksi dan mapping
  - Bokeh: untuk plot interaktif pada browser
  - Seaborn: untuk high level interface visualization

OpenCV

- OpenCV (open source computer vision library) adalah paket untuk aplikasi computer vision
- Memiliki berbagai macam interfaces (c++, python, java, matlab)
- Mendukung berbagai macem OS (windows, linux, mac, android)
- Dirancang untuk aplikasi real-time

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Pemrosesan Gambar

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Membaca gambar

- Membaca terhadap filepath tertentu dapat menggunakan cv2.imread
- Gambar pada opencv akan direpresentasikan dalam bentuk numpy array

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Channel dan format

- Shape dari gambar tersebut berbentuk (tinggi, lebar, warna BGR)
- Ini dikarenakan opencv memperlakukan gambar seperti rows (tinggi) dan column (lebar) pada numpy
- Konvensi ini mungkin akan berbeda dengan kesepakatan paket tensor lain!!!
- Warna apapun dikonstruksi sebagai kombinasi 3 warna dasar (subjective color) dengan urutan: blue, green, red

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Menampilkan gambar

- Untuk menampilkan gambar dapat menggunakan cv2.imshow (tidak berlaku untuk jupyter)
- Untuk jupyter gunakan plt.imshow

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Operasi dasar

- Untuk mengubah gambar berwarna menjadi abu-abu gunakan cvtColor
- Grayscale tidak mempunyai dimensi warna, namun setiap pixel memiliki luminosity diantara 0 dan 255
- Untuk mengubah ukuran gambar gunakan resize (tapi kali ini menggunakan konvensi lebar lalu tinggi)

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Menulis Gambar

- Gambar dapat ditulis kedalam sebuah file atau variable dengan imwrite

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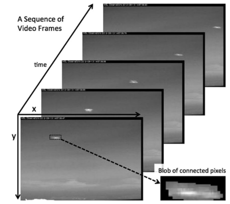
Video

- Video sebenarnya hanyalah sebuah urutan-urutan gambar
- Untuk membaca video dari webcams, IP cameras, atau file, kita dapat menggunakan VideoCapture
- Untuk menuliskannya dalam file, kita dapat menggunakan VideoWriter



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Thresholding

104	223	50
12	255	0
46	120	100

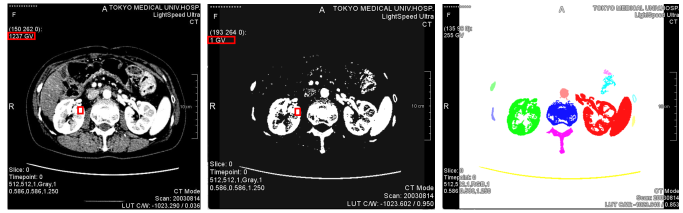
T=100

1	1	0
0	1	0
0	1	1

- Binary thresholding memaksa gambar menjadi 2 nilai.
- Binary thresholding dapat digunakan untuk memperoleh mask.

Thresholding

- Thresholding juga dapat digunakan untuk keperluan segmentasi



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Gaussian Blur

- Fungsi gaussian dapat dipakai untuk merata-rata suatu posisi dengan nilai terdekatnya
- Ini akan menghasilkan efek blur pada gambar

Original image **Gaussian Blur filter applied**

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Summary

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CALVIN INSTITUTE OF TECHNOLOGY
God's People for God's Glory

Deteksi Batas dan Garis

IBDA4311 – *Computer Vision*

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Capaian Pembelajaran

- Deteksi Batas Edge Detection
- Deteksi Garis line Detection

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Deteksi Batas

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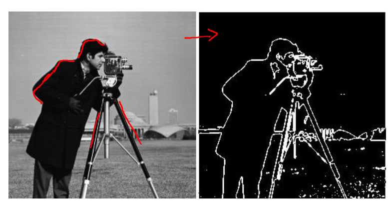
Garis Batas

- Sistem visual manusia berdasarkan garis batas
- Kita dapat mengidentifikasi sebuah objek dengan hanya menggunakan garis batas



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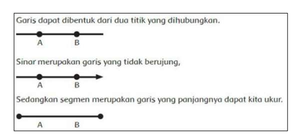
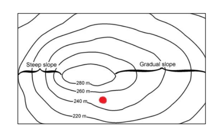
Tujuan Deteksi Batas

tensor
curve

1. Memetakan gambar (kumpulan pixel 2D) menjadi himpunan kurva, segmen garis, atau kontur
2. Representasi lebih padat dari sekedar gambar yang lengkap





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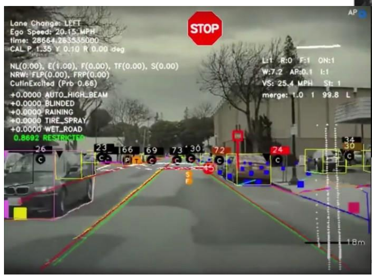
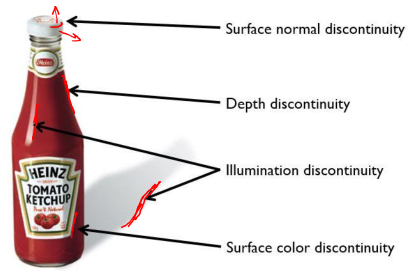
Aplikasi Modern

1. Lane Detection (self driving car)
2. Sistem Navigasi Helikopter

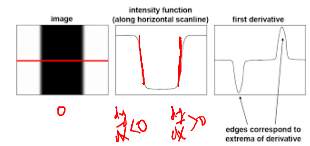


Apa saja yang menyebabkan batas



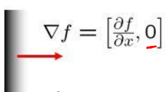
Turunan dan Batas

- Sebuah batas (edge) adalah tempat terjadinya perubahan drastis pada intensitas gambar

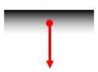


Gradien Gambar

- Gradien dari sebuah gambar: $\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$ turunan parsial
- Gradien mengarah pada perubahan intensitas yang paling besar



$\nabla f = \left[\frac{\partial f}{\partial x}, 0\right]$



$\nabla f = \left[0, \frac{\partial f}{\partial y}\right]$

$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$

- Arah dari gradien (arah normal dari batas) dideskripsikan oleh: $\theta = \tan^{-1}\left(\frac{\partial f}{\partial x} / \frac{\partial f}{\partial y}\right)$
- Kekuatan batas diberikan oleh nilai dari gradien $\|\nabla f\| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$

Turunan dan Konvolusi

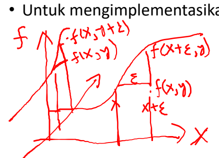
- Untuk fungsi 2D, $f(x,y)$, turunan parsial adalah:

$$\frac{\partial f(x,y)}{\partial x} = \lim_{\epsilon \to 0} \frac{f(x+\epsilon, y) - f(x,y)}{\epsilon}$$

- Untuk data diskrit, kita dapat menggunakan finite difference:

$$\frac{\partial f(x,y)}{\partial x} = \frac{f(x+1,y) - f(x,y)}{\Delta x}$$

- Untuk mengimplementasikannya sebagai konvolusi, filter apakah yang sesuai?



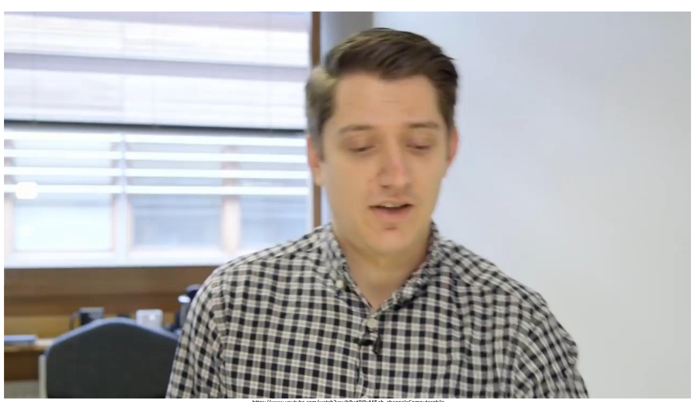
Filter finite difference

konvolusi

Prewitt: $M_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$; $M_y = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}$

Sobel: $M_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$; $M_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$

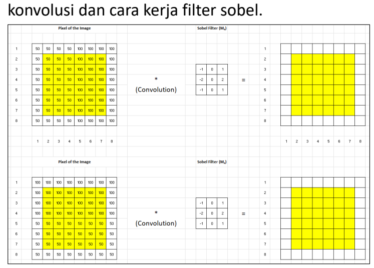
Roberts: $M_x = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$; $M_y = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$



https://www.youtube.com/watch?v=uihBwtPIBxM&ab_channel=Computerphile

Soal Latihan

- Kerjakanlah soal di dalam file SobelFilter.xlsx untuk lebih memahami mengenai konvolusi dan cara kerja filter sobel.

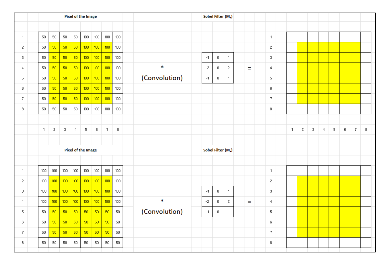


Sobel: $M_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$

$M_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$

Jawaban Latihan

- 1 orang mahasiswa/i mempresentasikan hasilnya



Sobel: $M_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$

$M_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$

Uji Pemahaman

- Batas apakah yang ditangkap filter-filter sebelumnya?

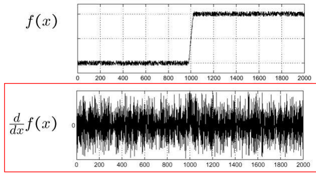
Prewitt: $M_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$; $M_y = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}$

Sobel: $M_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$; $M_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$

Roberts: $M_x = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$; $M_y = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$

Noise

- Misalkan kita mengambil satu baris dari gambar, lalu plot intensitas sebagai fungsi dari posisi:

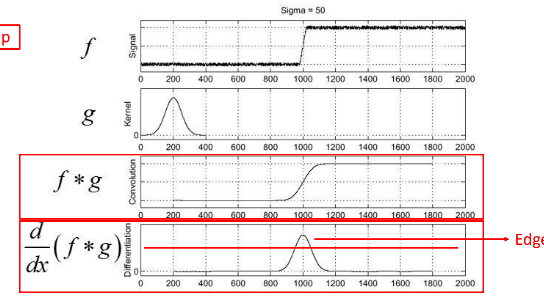


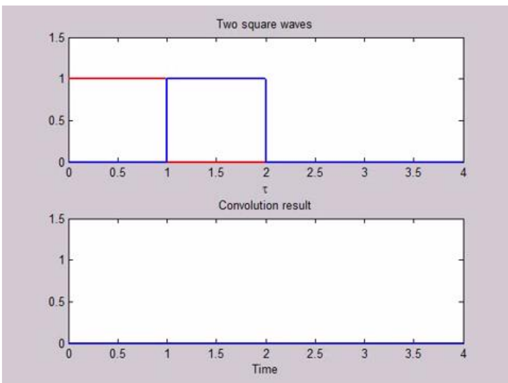
Inilah hasil turunan dari f(x) -> Dimanakah *edge*/batasnya?

- Finite difference berespon terlalu kuat terhadap noise (image noise berbentuk pixel yang sangat berbeda dengan pixel tetangganya)
- Apa yang harus dilakukan?

Smoothing

2 Step



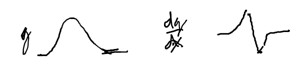


https://www.youtube.com/watch?v=HW4IamyQnzw&ab_channel=curtingareth

Animation of Convolution of Two Time Signals

https://www.youtube.com/watch?v=C1N55M1VD2o&ab_channel=YangCao

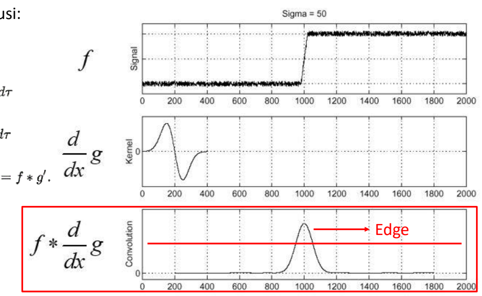
Turunan dari konvolusi



1 Step

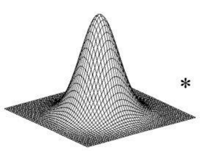
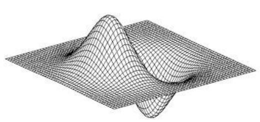
- Sifat turunan dari konvolusi:
- $\frac{\partial (f*g)}{\partial x} = f * \frac{\partial}{\partial x} g$

$$(f*g)' = \frac{d}{dt}\int_{-\infty}^{\infty} f(\tau) g(t-\tau)\, d\tau$$
$$= \int_{-\infty}^{\infty} f(\tau) \frac{\partial}{\partial t} g(t-\tau)\, d\tau$$
$$= \int_{-\infty}^{\infty} f(\tau) g'(t-\tau)\, d\tau = f * g'.$$



Turunan dari filter gaussian

- Apakah filter ini dapat dipisahkan?

 $* \begin{bmatrix} 1 & -1 \end{bmatrix} =$ 

- Ya, kita dapat memisahkannya menjadi 2 buah filter yang urutannya tidak penting
- Median filter adalah contoh sebuah filter yang tidak dapat dipisahkan

Median Filter

8	9	10	11	12
12	8	9	10	11
13	12	8	9	10
14	12	12	8	9
15	14	13	12	8

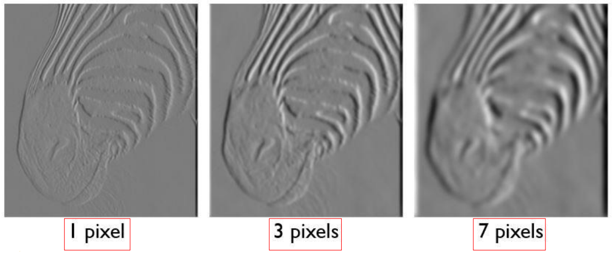
https://www.youtube.com/watch?v=3kwH3Rb5LJ4&ab_channel=CODEROOM

Median Filter

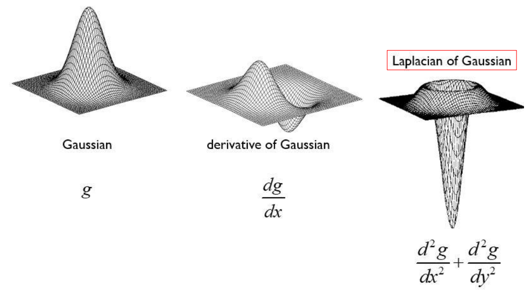
- Median filter adalah contoh dari filter yang tidak dapat dipisahkan karena ia menggunakan informasi spasial dari data inputnya untuk menghasilkan outputnya.
- Filter yang tidak dapat dipisahkan adalah jenis filter yang tidak dapat diwakilkan oleh fungsi matematis tunggal. Sebaliknya, jenis filter ini memerlukan pemrosesan data yang bergantung pada konteks lokal di sekitarnya.

Smoothing tradeoffs

- Turunan yang dihaluskan menghilangkan noise, tapi blur batas
- Batas dapat ditemukan dalam skala yang berbeda

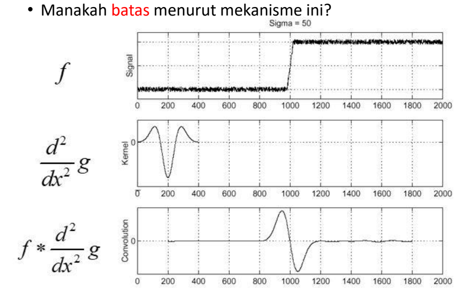


Filter deteksi batas



Laplacian of Gaussian (LoG)

- Manakah batas menurut mekanisme ini?



1	1	1
1	-8	1
1	1	1

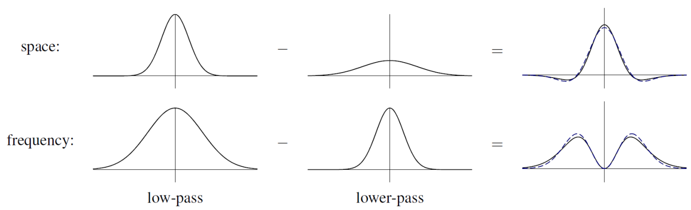
Difference of Gaussians

MATLAB

https://www.youtube.com/watch?v=2Spziw4QtmI&ab_channel=KnowledgeAmplifier

Difference of Gaussians (DoG)

- DoG dapat mengaproksimasi LoG secara cukup baik
  - LoG (dashed blue) vs DoG (black)



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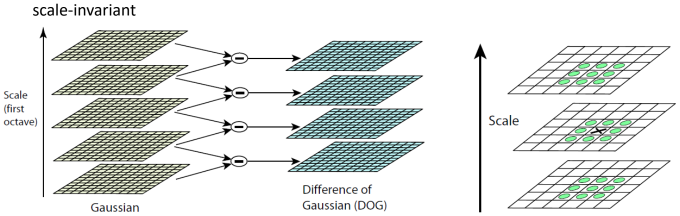
Deteksi Batas dan Garis

IBDA4311 – *Computer Vision*

Piramida Gaussian dan DoG

- DoG biasanya digunakan untuk piramida gaussian untuk deteksi fitur yang bersifat scale-invariant



(a) (b)

Apakah deteksi batas yang baik?

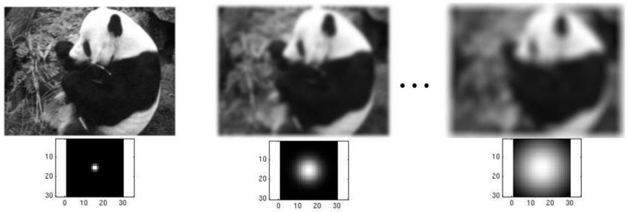
- Deteksi:
  - Meminimalkan false positives (deteksi yang salah)
  - Meminimalkan false negatives (gagal mendeteksi batas sebenarnya)
  - Memaksimalkan deteksi yang benar
- Lokalisasi:
  - Batas yang terdeteksi harus sedekat mungkin dengan batas yang benar
- Respon tunggal:
  - Menghasilkan satu respons untuk setiap posisi batas yang benar
- Menghubungkan deteksi ke garis

Apa sajakah parameter dalam deteksi batas?

- Skala
- Threshold

Pemilihan skala

- Kita menghaluskan image dengan kernel gaussian untuk mengurangi noise
- Skala Gaussian menentukan seberapa halus



Efek dari skala terhadap turunan

- Hasil berbeda tergantung skala Gaussian
- Skala besar: deteksi batas berskala besar
- Skala kecil: deteksi batas yang lebih tipis

σ = 1 pixel σ = 3 pixels

Bagaimana memilih skala?

- Tergantung dari apa yang kita cari
- Skala terlalu kecil: tidak bisa melihat hal besar
- Skala terlalu besar: tidak dapat membedakan hal-hal tipis

Threshold

- Pilih sebuah nilai threshold
- Tentukan gradien apapun diantara 0 sampai nilai tersebut (off)
- Tentukan gradien apapun diantara nilai tersebut sampai 1 (on)

Canny edge detector

- Deteksi batas yang paling umum digunakan di computer vision
- Deteksi step-edges yang dirusak oleh gaussian noise

Canny edge detector

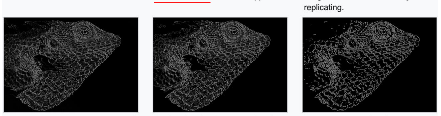
- Filter gambar dengan turunan gaussian
- Menemukan orientasi dan besar dari gradien
- Non-maximum suppression: (lokalisasi)
  - Dimulai dari riak dengan lebar multi-pixel sampai lebar 1 pixel
- Linking and thresholding:
  - Tentukan 2 thresholds: low dan high
  - Gunakan threshold yang lebih tinggi untuk membuat garis batas lalu lanjutkan dengan threshold yang lebih rendah
- Cv2.Canny()

Canny edge detector

The original image

Image has been reduced to grayscale, and a 5x5 Gaussian filter with σ=1.4 has been applied

The intensity gradient of the previous image. The edges of the image have been handled by replicating.

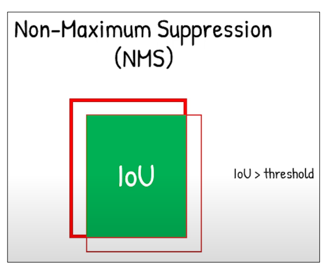


Non-maximum suppression applied to the previous image.

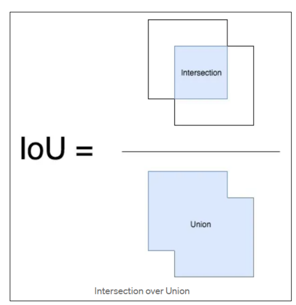
Double thresholding applied to the previous image. Weak pixels are those with a gradient value between 0.1 and 0.3. Strong pixels have a gradient value greater than 0.3

Hysteresis applied to the previous image

Non-Maximum Suppression (NMS)



https://www.youtube.com/watch?v=lYLya1aQmrU&ab_channel=AnakAI



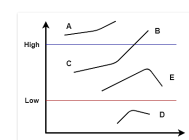
https://towardsdatascience.com/non-maximum-suppression-nms-93ce178e177c

Hysteresis Thresholding

Non-max suppression outputs a more accurate representation of real edges in an image. But you can see that some edges are more bright than others. The brighter ones can be considered as strong edges but the lighter ones can actually be edges or they can be because of noise. To solve the problem of "which edges are really edges and which are not" Canny uses the Hysteresis thresholding. In this, we set two thresholds 'High' and 'Low'.

- Any edges with intensity greater than 'High' are the sure edges.
- Any edges with intensity less than 'Low' are sure to be non-edges.
- The edges between 'High' and 'Low' thresholds are classified as edges only if they are connected to a sure edge otherwise discarded.

Let's take an example to understand



Here, A and B are sure-edges as they are above 'High' threshold. Similarly, D is a sure non-edge. Both 'E' and 'C' are weak edges but since 'C' is connected to 'B' which is a sure edge, 'C' is also considered as a strong edge. Using the same logic 'E' is discarded. This way we will get only the strong edges in the image.

This is based on the assumption that the edges are long lines.

https://theailearner.com/tag/hysteresis-thresholding/

Deteksi Garis

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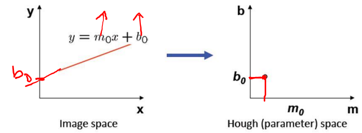
Line Fitting

Metode-metode yang dapat digunakan:

1. Hough Transform
2. RANSAC → deep learning
3. SCNN

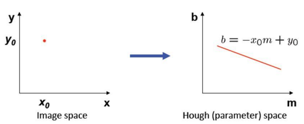
Hough Transform

- Transformasi image space (x,y) menuju Hough space (m,b)
- Sebuah garis pada gambar adalah sebuah titik pada hough space
- Hough: untuk himpunan poin (x,y) temukan semua (m,b) dimana y=mx+b

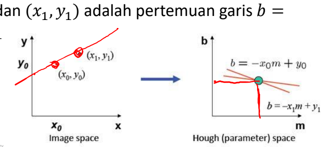


Hough Transform

- Sebuah titik (x_0, y_0) pada gambar adalah solusi dari $b = -x_0m + y_0$ (Titik -> Garis)

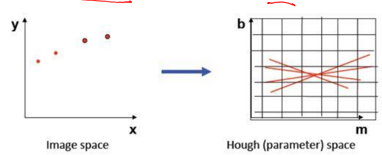


- Sebuah garis yang berisi titik (x_0, y_0) dan (x_1, y_1) adalah pertemuan garis $b = -x_0m + y_0$ dan garis $b = -x_1m + y_1$



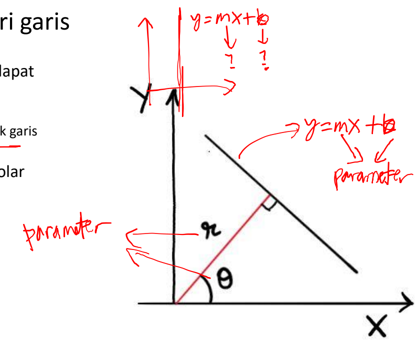
Menemukan garis dengan transformasi Hough

- Setiap titik batas voting untuk himpunan parameter mungkin pada Hough space
- Hitung votes pada sebuah himpunan diskrit
- Parameter dengan voting banyak mengindikasikan garis pada image space



Representasi polar dari garis

- Persamaan garis $y = mx + b$ dapat bermasalah, misalnya:
  1. Dapat bernilai tak hingga
  2. Tidak dapat didefinisikan untuk garis vertikal
- Solusi: gunakan representasi polar

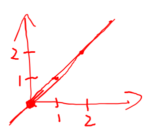


Uji Pemahaman

- Apakah representasi polar dari garis $y = x$ → y = mx+b
  = 1x + 0

r, θ

0 45°

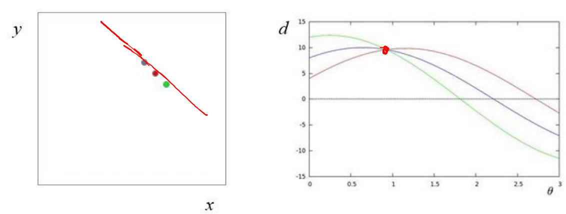


Contoh Transformasi Hough

- Untuk suatu titik (x_0, y_0)

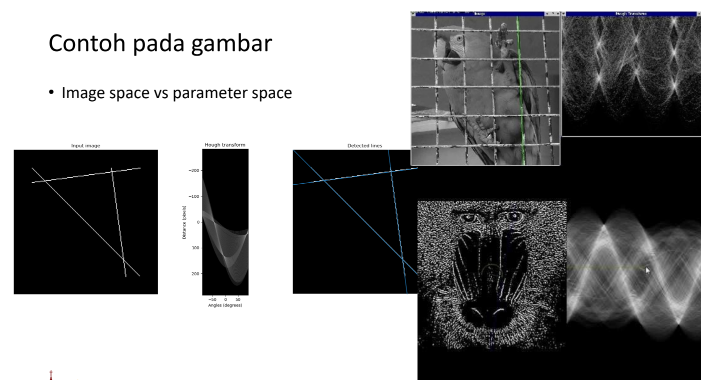
$$r(\theta) = x_0 \cos\theta + y_0 \sin\theta$$

- Untuk 3 titik sepanjang garis $(d \equiv r)$



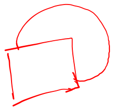
Contoh pada gambar

- Image space vs parameter space

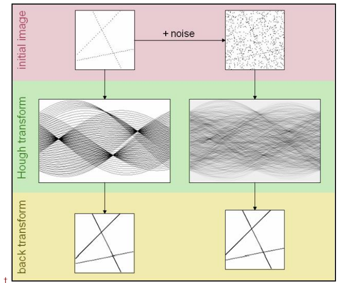


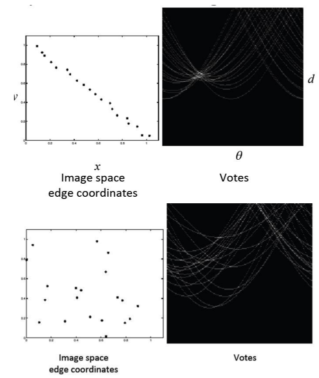
Sifat Transformasi Hough

- Noise dan clutter votes tidak konsisten sehingga tidak akan terakumulasi
- Dapat mengatur occlusion selama model menerima cukup banyak votes
- Efisien



Noise pada Transformasi Hough





Kelebihan dan Kekurangan Transformasi Hough

- **Kelebihan**
  - Dapat menerima occlusions
  - Robust terhadap noise
  - Dapat mendeteksi beberapa garis sekaligus dalam sekali proses gambar
- **Kekurangan**
  - Kompleksitas meningkat eksponensial sesuai jumlah parameter → garis → 2p

Ransac

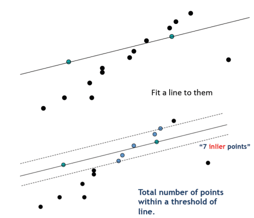
- **RAN**dom **SA**mple **C**onsensus [Fischler & Bolles 1981]
- Cari "inliers" dan hanya gunakan ini
- Jika kita fit sebuah model pada "outliers" kita tidak akan memperoleh fit yang sesuai

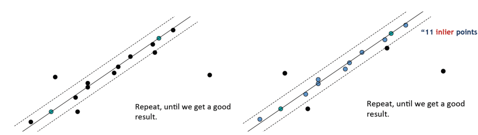
Algoritma Ransac

1. Loop:
   a. Pilih secara acak kumpulan titik
   b. Fit sebuah model terhadap pilihan tersebut
   c. Temukan inliers dari model yang sudah dihitung
   d. Jika jumlah inliers sudah cukup besar, hitung ulang model dengan hanya menggunakan inliers
   e. Hitung jumlah inliers dari model yang sudah diperbaharui
2. Yang dipilih: model dengan jumlah inliers terbanyak

Contoh Algoritma RANSAC

1. Data input: kumpulan titik
2. Step 1: pilih 2 titik
3. Step 2: fit garis pada titik-titik tersebut
4. Step 3: temukan inliers
5. Step 4: ulangi step 1-3 sampe konvergen





Kriteria Stop

Opsi 1: Ketika model sudah cukup baik
- Menurut jumlah inliers
- Menurut fitting error

Opsi 2: menurut peluang
- Misalkan K adalah jumlah iterasi
- Misalkan n adalah jumlah titik yang diperlukan untuk menghitung model
- Misalkan f adalah fraksi inliers dari sebuah model
- Maka peluang sebuah sampel benar adalah: f_n
- Peluang bahwa semua sampel K gagal adalah: $(1 - f_n)^K$
- Pilih nilai K cukup tinggi untuk menjaga tingkat kegagalan rendah

Implementasi

- OpenCV menggunakan Homografi: cv2.findHomography(src_pts, dst_pts, cv2_RANSAC)
- Scikit-image menggunakan: skimage.measure.ransac()
- Scikit-learn menggunakan: sklearn.linear_model.RANSACRegressor()

Kelebihan dan Kekurangan

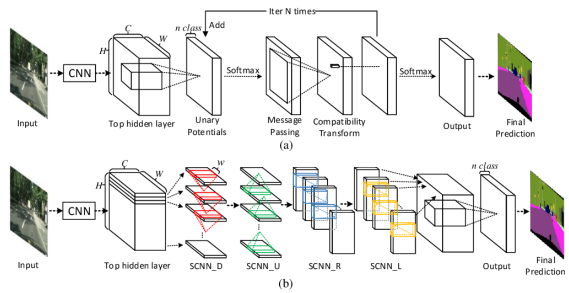
Kelebihan
- Metode umum yang bekerja cukup baik untuk berbagai jenis masalah model fitting
- Mudah diimplementasikan

Kekurangan
- Situasi dimana persentase outliers banyak sehingga butuh banyak iterasi dan tingkat kegagalan meningkat

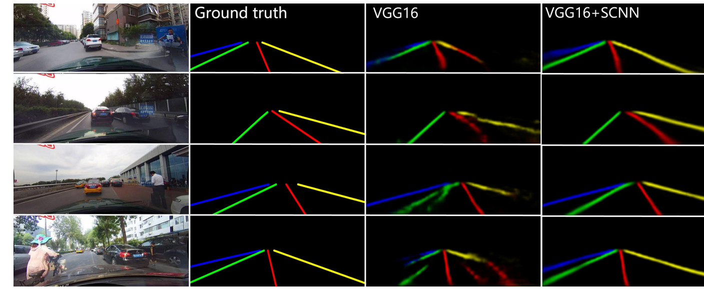
SCNN

- Spatial Convolutional Neural Network
- CNN Klasik tidak memiliki pengertian spasial: tidak dapat menangkap relasi spasial (rotasi dan translasi)
- Relasi spatial memiliki banyak kegunaan:
  - Lampu lalu lintas umumnya memiliki relasi spasial seperti berdiri vertikal dan diletakan di kiri atau kanan jalan
  - Identifikasi lajur

Arsitektur SCNN



Contoh SCNN



Summary

Edge detection
- Filter
- Turunan, konvolusi, Gaussian blur, LoG, DoG
- Canny Detection

Line detection
- Hough transform
- RANSAC
- SCNN

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IBDA4311 Computer Vision

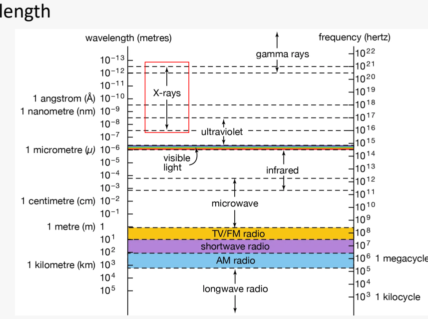
Topik Minggu Ini dan Capaian Pembelajaran

Topik minggu ini:
1. Pemrosesan Gambar Medis (*Medical Image Processing*)

Capaian Pembelajaran:
1. Mahasiswa mampu mengaplikasikan konsep-konsep pemrosesan gambar medis

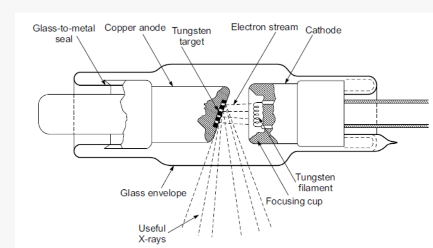
X-Ray

X-Rays Wavelength



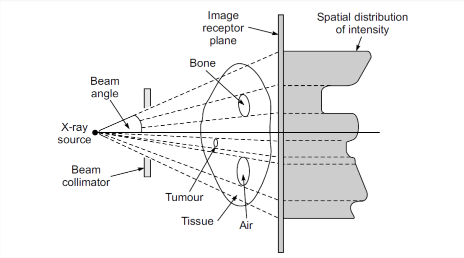
Sumber: Encyclopedia Britannica, Inc.

Construction Of Stationary X-Ray Anode Tube



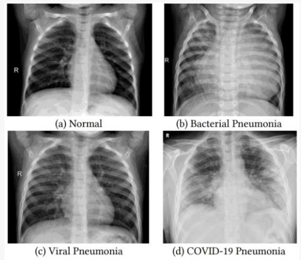
Sumber: "Handbook of Biomedical Instrumentation", Third Edition, Author: Dr. R. S. Khandpur, Publisher McGraw Hill Education, ISBN: 9789339205430.

Basis Of Diagnostic Radiology



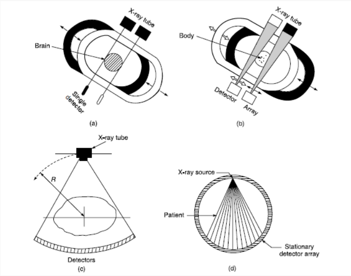
Gambar: Basic set up for a diagnostic radiology image formation process. Sumber: "Handbook of Biomedical Instrumentation", Third Edition.

X-Ray Images



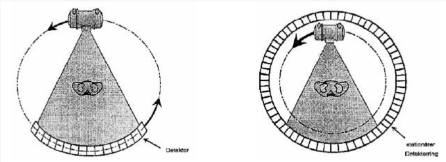
Computed Tomography (CT)

I. Scanning System: Scanning Arrangements



Gambar: Scanning arrangement of the early CT machines. Sumber: "Handbook of Biomedical Instrumentation", Third Edition.

II. Processing System: Gantry Geometry

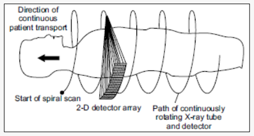


Sumber: Friedrich Ueberle

Video: Inside Of CT Scanner At Full Speed

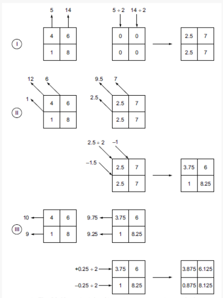
Sumber: https://www.youtube.com/watch?v=pLajmU4TQuI&ab_channel=Newsflare

I. Scanning System: Scanning Arrangements



Gambar: The spiral CT scan principle in multislice scanning. Sumber: "Handbook of Biomedical Instrumentation", Third Edition.

II. Processing System: Processing Unit



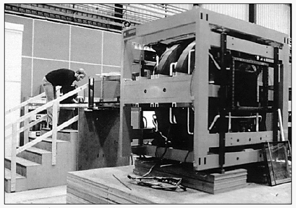
➤ Fig. 20.16 *Principle of iterative reconstruction method*

Gambar: Principle of the iterative reconstruction method. Sumber: "Handbook of Biomedical Instrumentation", Third Edition.

CT Images

Magnetic Resonance Imaging (MRI)

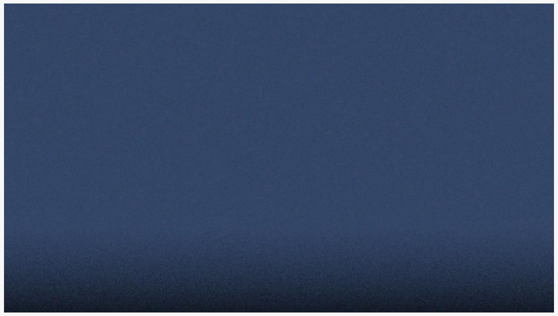
History Of MRI



Gambar: The 1st 0.15 Tesla MRI Prototype from Philips was put into operation in 1979. Sumber: Friedrich Ueberle

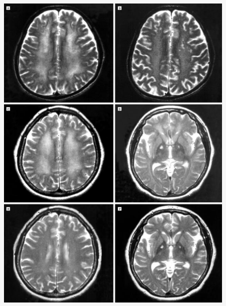
Gambar: 4th Generation and High Power 3 Tesla MRI scanner Skyra Magnetom from Siemens.
Sumber: https://www.metropolitan-general.gr/en/media2/photos/2016-ultra-modern-3-tesla-m-r-i-machine

Video: How MRI Machine Works



Sumber: https://www.youtube.com/watch?v=g-jj4KrmYPI&ab_channel=SiemensHealthineers

MRI Images



Ultrasonic Imaging Systems

Ultrasound Procedures

Ultrasound Images

Impedansi Karakteristik

Impedansi karakteristik atau impedansi akustik spesifik suatu medium didefinisikan sebagai produk kerapatan medium dengan kecepatan suara dalam medium yang sama.

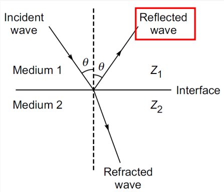
$$z = \rho V$$

where z = specific acoustic impedance
ρ = density of the medium
V = velocity of sound in the medium.

Impedansi karakteristik menentukan derajat pemantulan dan pembiasan pada antarmuka antara dua media. Persentase energi gelombang datang yang dipantulkan digambarkan oleh rumus berikut ini:

$$\left[\frac{z_1 - z_2}{z_1 + z_2}\right]^2 \times 100\%$$

where z_1 = acoustic impedance of medium 1
z_2 = acoustic impedance of medium 2

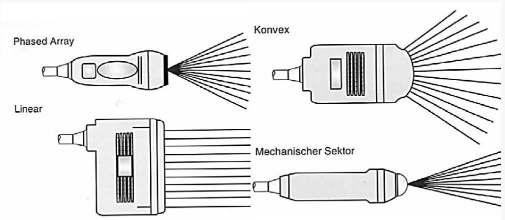


Gambar: Pemantulan dan pembiasan ultrasonik pada antarmuka antara dua media yang memiliki impedansi akustik yang berbeda.
Sumber: Handbook of Biomedical Instrumentation

Anatomy of USG

Probe dengan prinsip konverter yang berbeda:

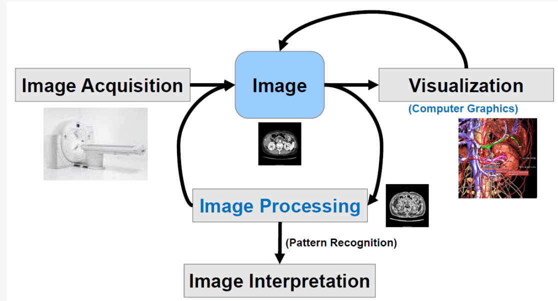
- Phased Array: Kontrol fokus dan arah dilakukan sepenuhnya oleh elektronik. Semua elemen dinyalakan bersama-sama sekaligus
- Linear Array: Grup-grup dari elemen dinyalakan secara bergantian
- Konvex Array: Grup-grup dari elemen dinyalakan secara bergantian seperti Linear Array, tetapi pancaran berbentuk kipas
- Mechanical Sector: Elemen tunggal berporos motor



Sumber: Friedrich Ueberle

Medical Image Processing

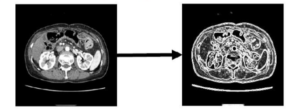
Image Workflow



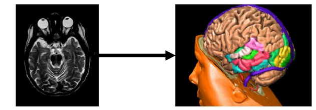
Courtesy: Prof. Dr.-Ing. Thomas Schiemann

2 Examples

- Image Processing: Edge Detection



- Computer Graphics: 3D Visualization of MRI

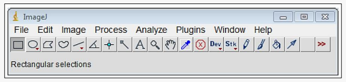


VOXEL-MAN, University Hospital Hamburg-Eppendorf

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

ImageJ -> Install

- Image processing software with emphasis on medical and scientific applications
- Set of basic functions available
- Written in Java, offers Programming interface for own methods (**Plugins**)
- Open source: http://rsbweb.nih.gov/ij
- Download 64-bit Java for Windows: https://www.java.com/en/download/



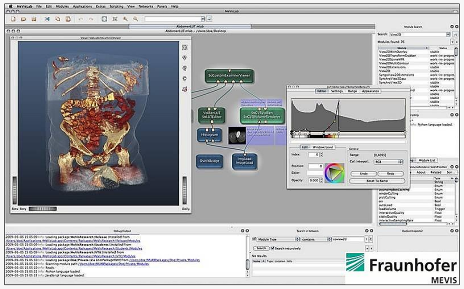
Courtesy: Prof. Dr.-Ing. Thomas Schiemann

MeVisLab -> Install

- Professional software for medical image processing and visualization.
- Programming interface for own methods (**modules**) in C++.
- Graphical programming of module networks
- Free license: http://www.mevislab.de/download
- https://ij.imjoy.io/

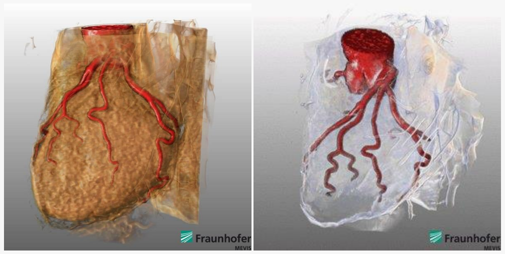
Courtesy: Prof. Dr.-Ing. Thomas Schiemann

MeVisLab



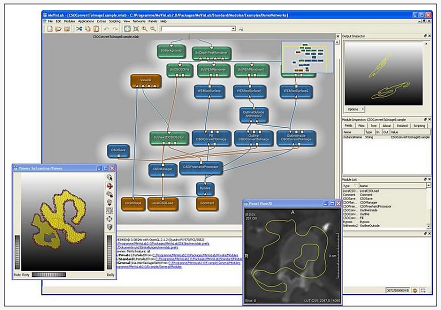
Source: https://www.mevislab.de/mevislab/screenshots/

MeVisLab



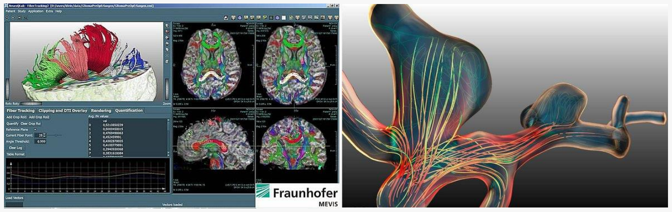
https://en.wikipedia.org/wiki/MeVisLab

MeVisLab



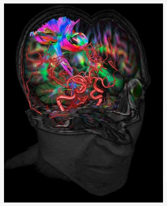
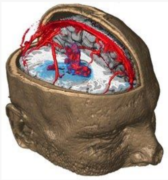
Source: Mevis Medical Solutions AG

MeVisLab



Source: https://www.mevislab.de/mevislab/screenshots/

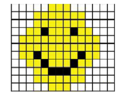
MeVisLab

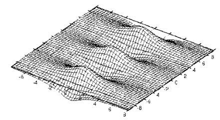

https://www.mevislab.de/mevislab/screenshots

What is an image?

- Grid or array of pixels (picture elements)
  - each pixel carries intensity or color information



- 2D (diskrete) function *f(x,y)*
  - function value: intensity or color information



Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Binary and gray value images

- 1 Bit: black and white = binary images

- 8 Bit: 256 gray values (0-255)
- 12 Bit: 4096 gray values
  used in CT: Hounsfield units -1024…3071
- 16 Bit: 65536 gray values

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Histograms

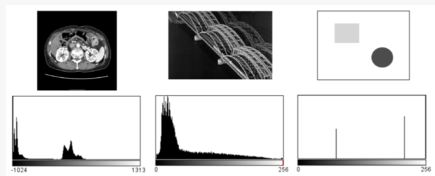
- Histograms show frequencies of intensities
  ("How many pixels are in the image with a certain intensity?")
- The information of a histogram can basically be represented in a list:

Intensity	Number of pixels
0	25898
1	7834
2	35
…	…

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Examples

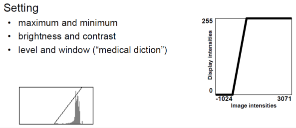
- Usually, histograms are displayed as bar-diagrams



Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Histogram based operations

- Selection of an intensity interval to be mapped onto the maximum and minimum intensities, which can be displayed,
  usually *max*=0, *min*=255.
- Setting
  - maximum and minimum
  - brightness and contrast
  - level and window ("medical diction")



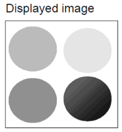
Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Example

Original image data

Setting contrast/brightness

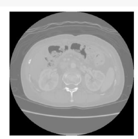
Displayed image



ImageJ: `Image - Adjust- Brightness/Contrast...`

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Computer Tomography



Original data

„clothes window"

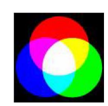
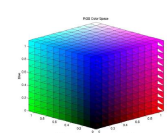
soft-tissue window

bone window

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

RGB-Color-Model

- Colors are defined by addition of the three basic colors red, green and blue
- grey/white = red+green+blue in equal percentages
- colors = p_1*red + p_2*green + p_3*blue

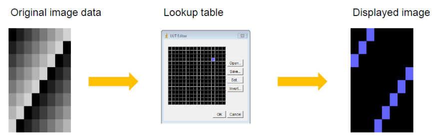



Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Lookup-Tables (LUT)

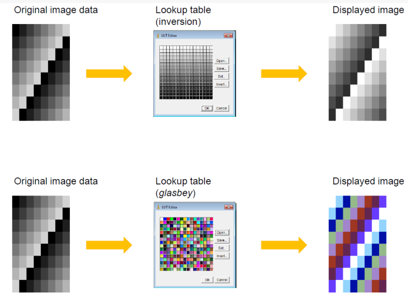
- Lookup-tables assign a new intensity or color to each original intensity

Example 1:

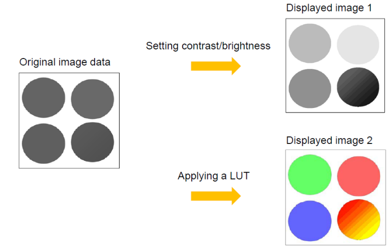


ImageJ: `Image - Color - Edit LUT...`

Examples



Examples

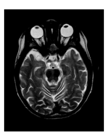


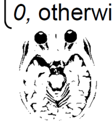
ImageJ: `Image - Adjust- Brightness/Contrast...`

Threshold

- Gray value images $I(x,y)$ can be converted to binary images $B(x,y)$ by setting a lower threshold t_1 and an upper threshold t_2 $(t_1 \leq t_2)$:

$$B(x,y) = \begin{cases} 1, \text{ if } t_1 \leq I(x,y) \leq t_2 \\ 0, \text{ otherwise} \end{cases}$$





Latihan

Kerjakanlah Latihan Minggu 5_1

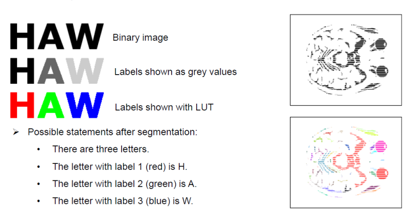
Medical Image Processing: Segmentation Problem

The Segmentation Problem

- Questions on an image of the abdomen:
  - Does pixel (40,320) belong the the liver?
  - Which is the area/volume of the liver?
  - Which is the center of mass of the liver?
  - Which is the distance of the liver from the spine?
  - How many different anatomical structures can be seen on the image?
- We need a layer of additonal information.

The Segmentation Problem

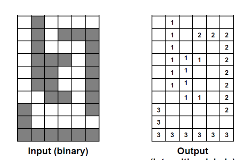
- Basis: Assigning labels (numbers) to groups of connected pixels.



- Possible statements after segmentation:
  - There are three letters.
  - The letter with label 1 (red) is H.
  - The letter with label 2 (green) is A.
  - The letter with label 3 (blue) is W.
  - ...

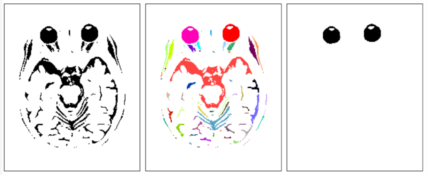
Region Labelling

- Methods for region labeling use a binary input-image and create a grey-value output-image, where groups of connected pixels (=regions) have the same intensity (=label).
- Example:



Example

- Example: Segmentation of the eyes

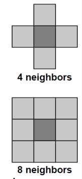


1. binary image 2. labeled regions 3. selected regions

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Connectivity

- There are 2 important types of connectivity:
  1. Only connectivity via an edge is considered. Then an inner pixel has 4 neighbors.
  2. Also connectivity via a corner is considered. Then an inner pixel has 8 neighbors.
  - Boundary pixels have less neighbors.
  - Other types of connectivity may also consider neighbors with a distance larger than 1.

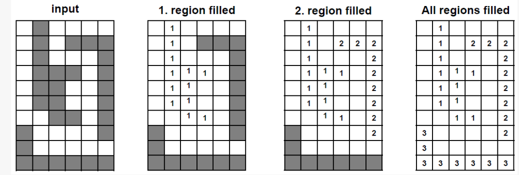


- Using the 4-neighborhood is quicker and results in more separated regions, which is usually preferable in segmentation problems.

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Method 1: Flood Filling

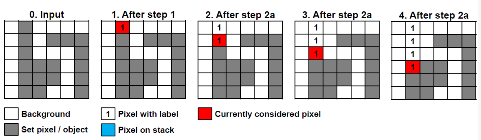
- Find the next set pixel without a label
- Label this pixel and all connected pixels with the same label
- Recursive programming or administration of a stack



Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Steps

0. Set the current label-value to 1 and start at pixel (0,0)
1. Find the first (or next) set and unlabeled pixel and assign the current label-value to this pixel
2. Check all neighbors:
   a: **Just one neighbor** is set, unlabeled and not stored on stack
   Move to this neighbor, assign the current label and continue at 2.



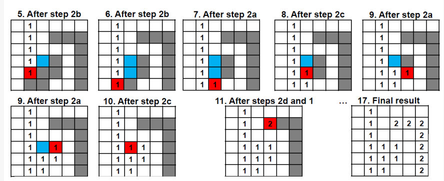
Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Steps

b: $N \geq 2$ **neighbors** are set, unlabeled and not stored on stack
Put *N-2* neighbors on stack
Move to 1 neighbor, assign the current label and continue at 2.

c: No set neighbors and unlabeled neighbors, but **stack filled**
Take pixel from stack
Move to this pixel, assign the current label and continue at 2

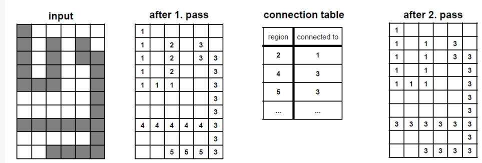
d: No set and unlabeled neighbors, and **stack empty**
Increase the current label-value and continue at 1



Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Method 2: Sequential Filling

- Move through the whole image in a sequential order
- Assign the lowest label of the neighborhood to each pixel or assign a new label, if all neighbors are unlabeled.
- administration of a connection table
- 2 passes through the image



Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Binary Morphological Operations

- Basic operations: dilation and erosion
- Composed operations: opening and closing
- The operations are controlled by a structuring element, which can be regarded as a (small) binary image
  - typical structuring elements:

0	0	0	0	0
0	0	1	0	0
0	1	1	1	0
0	0	1	0	0
0	0	0	0	0

0	0	0	0	0
0	1	1	1	0
0	1	1	1	0
0	1	1	1	0
0	0	0	0	0

0	0	1	0	0
0	1	1	1	0
1	1	1	1	1
0	1	1	1	0
0	0	1	0	0

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Dilation

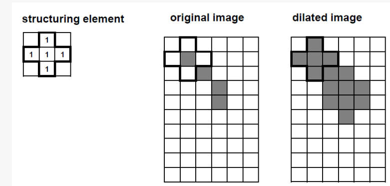
- The structuring element is positioned at every 1-pixel of the (binary) image.
- Every 0-pixel of the image, which is hit by a 1 of the structuring element is set to 1.
- Dilation widens structures.

Example: Dilation by 3x3 box

letters **letters**

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Dilation Example



Courtesy: Prof. Dr.-Ing. Thomas Schiemann

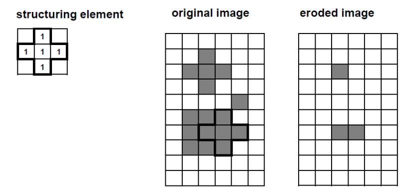
Erosion

- The structuring element is positioned at every 1-pixel of the (binary) image.
- If a 1 of the structuring element hits a 0 of the image, the image is set to 0 at the center of the structuring element.
- "Dilation of the background"
- Erosion narrows structures.

Example: Erosion by 3x3 box

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Erosion Example



Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Opening

- Opening = 1. Erosion, 2. Dilation
- Erosion and Dilation are "opposite" operations, but they are not inverse.
- Only those pixels are left in the image, which are covered by a 1 of the structuring element, while it is completely located on 1-pixels of the image.
- The structuring element stamps its shape onto the original structures.

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Opening

Example: Opening by 3x3 box

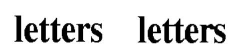
Example: Opening of a square object by a circular structuring element

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Closing

- Closing = 1. Dilation, 2. Erosion
- Opening of the background
- Filling of holes, which are smaller or equal to the structuring element.

Example: Closing by 3x3 box



Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Applications

- Finding boundaries
  1. Erosion
  2. Subtract erosion-output from input
- Separating objects from each other (Segmentation)
- Removal of small objects (opening)
- Filling of small holes (closing)
- (Finding objects of a certain shape)

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Morphological Operations in Formulas

Let *I* be the image, *S* the structuring element, and I_{ij} the image shifted *i* pixels in *x*-direction and *j* pixels in *y*-direction.
(The origin of the coordinate-system is usually located in the top left corner)

Then the dilation can be defined as

$$I \oplus S = \bigcup_{(i,j) \in S} I_{(-i,-j)} \quad \text{(Union of all shifted images)}$$

and erosion as

$$I \ominus S = \bigcap_{(i,j) \in S} I_{(-i,-j)} \quad \text{(Intersection of all shifted images)}$$

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Grey-Value Morphological Operations

The image I and the structuring element S both are containing grey-values now.

Then the dilation is defined as

$$(I \oplus S)(x,y) = \max_{(i,j) \in S} \{I(x+i, y+j) + S(i,j)\}$$

and erosion as

$$(I \ominus S)(x,y) = \min_{(i,j) \in S} \{I(x+i, y+j) - S(i,j)\}$$

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Example

Image (sourrounded by zeros)

7	6	3	5
5	6	2	3
5	9	3	2
3	5	7	7

Structuring Element

2	1	0
0	3	1
0	0	4

Structuring element positioned at (1,1) for dilation

9	7	3	5
5	9	3	3
5	9	7	2
3	5	7	7

Dilation

10	9	7	8
13	9	8	6
10	12	11	5
6	10	11	10

Erosion

2	-2	-1	2
2	-1	-2	0
1	2	0	-1
0	2	2	1

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Special Case: Maximum-Filter

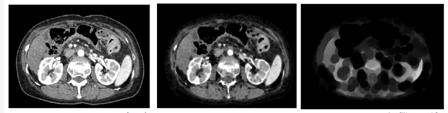
- The maximum filter is the grey-value *dilation* with a structuring element filled by zeros.
- Each pixel is the replaced by the maximum intensity of its neighborhood, which is defined by the structuring element.

input max-filter, r=2 max-filter, r=12

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Special Case: Minimum-Filter

- The minimum filter is the grey-value *erosion* with a structuring element filled by zeros.
- Each pixel is the replaced by the minimum intensity of its neighborhood, which is defined by the structuring element.



input min-filter, r=2 min-filter, r=12

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

Latihan

Kerjakanlah Latihan Minggu 5_2 dan kumpulkanlah jawaban anda dalam Canvas

Courtesy: Prof. Dr.-Ing. Thomas Schiemann

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Tuhan Memberkati