

Prof. dr Dragan Ivetić

RAČUNARSKA GRAFIKA

skripta

DVADESETDRUGA GENERACIJA STUDENATA



Novi Sad, 2022. godine

Kome i kako?

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RAČUNARSKA GRAFIKA, 3 + 2 (na FTN od 2001./2002. školske godine)

Dr Dragan Ivetić, redovni profesor

Nedeljko Tešanović i Jovan Ivošević



E2 Primjenjene računarske nake i informatika, 7. semestar
Animacija u inženjerstvu (ANI), 3. semestar

Kako položiti predmet?

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1. Predispitne obaveze, do 70 bodova:

vežbe (C/C++ & OpenGL 3.3) – 50 bodova + deskriptor.

mini teorija (testovi u 1 ili 2 navrata) – 20 bodova,

Potpis ako se osvoji više od 35.7 predispitnih bodova.

2. Završni ispit (moguće dve isključive varijante)

1. **BEZ (vežbe>25, mini teor. >14 i nikada GIM) – 51..70**
(potpisana saglasnost u januaru, junu ili septembru)

2. **Usmeni 30 minuta (15.. 30), (vežbe>25), – 51 .. 100,**
termini na GIMu tokom JAN – MAJ pa NOV - DEC, 2
puta maksimalno, u suprotnom sve ponovo

O nastavniku



Dipl. ing. elek. - računarstvo i automatika, 1990, FTN,
 Mr teh. nauka - formalizmi u SE, 1994, FTN,
 Dr teh. nauka - integracija HCI i SE, 1999, FTN.
 DAAD, RWTH Aachen – Primena multim. u industriji, 1997.
 R. prof., FTN – elektrotehn. i računarstvo, 2010.

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Grafički i multimedijalni sistemi, šk. 2001./2002.
 Interakcija čovek računar, šk. 2002./2003.
 Kompresija podataka, šk. 2005./2006.
 Sistemi virtuelne realnosti, 2009./2010.
 Razvoj računarskih igara, šk. 2013./2014.



NTP 400, (021) 485 – 4571,

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Grupa za Grafiku, Interakciju i Multimediju

Početna Predmeti Članovi HCI studije Projekti Materijali Dragan Ivetić   

Računarska grafika (ANI)

Fond: 3+2 # Semestar: 3 Šk. god: 2020/2021 Smer: Animacija u inženjerstvu

Osnovni podaci

Kancelarija

Telefon

@ Email

Predavanja

prof. dr Dragan Ivetić

NTP 400

021/485-4571

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Vežbe

Nastavni materijali

Rezultati

Zakazivanje termina 

Slanje obaveštenja

Sadržaj po nedeljama semestra 

**Ulogovati se na
<http://gim.ftn.uns.ac.rs>
 sa AI xx/yyyy i ftn**

Početna | Predmeti | Članovi | Radovi | Projekti | Rezultati
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Literatura

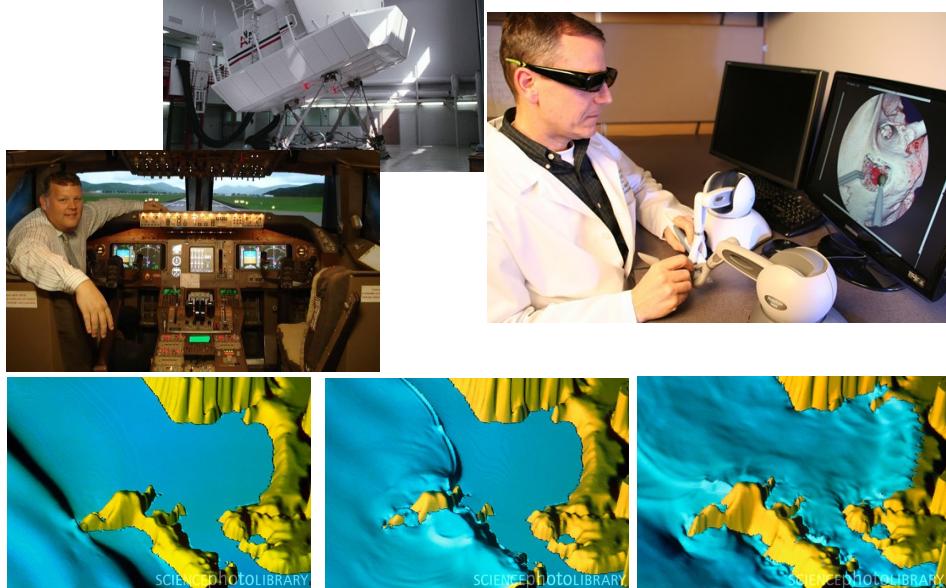
- 1. SLAJDOVI SA PREDAVANJA SA VAŠIM BELEŠKAMA**
2. Hughes, V. Dam, McGuire, Sklar, Foley, Feiner, & Akeley, COMPUTER GRAPHICS Principles and Practice, 2013.
3. Akenine-Möller T., Heines E. and Hoffman N, REAL-TIME RENDERING, 3rd Ed., 2008.
4. Sumanta Guha, Computer Graphics Through OpenGL From Theory to Experiments, 3rd Ed, CRC Pres, 2019.
5. Graham Sellers, Richard S. Wright, Nicholas Haemel, OpenGL Superbible: Comprehensive Tutorial and Reference, 7th Ed, Addison-Wesley, 2016.
6. Joey de Vries, Learn OpenGL: Learn modern OpenGL graphics programming in a step-by-step fashion, <https://learnopengl.com/>, 2020.

Oblasti računarske grafike

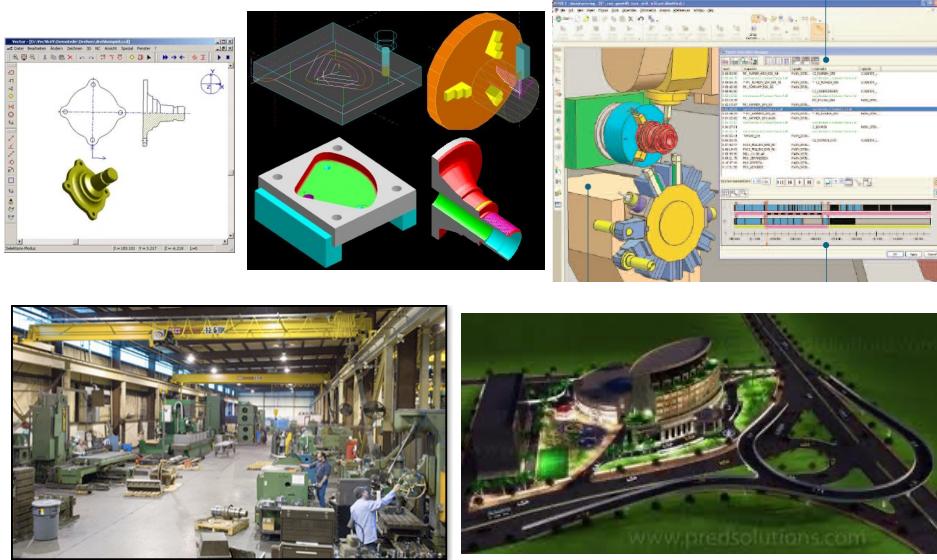
su:

- *Generativna grafika*
 - konstrukcija objekata i generisanje slike,
 - transformacija objekata i slike,
 - identifikacija objekata i info. retrieval
- *Obrada i analiza slike*
 - unapređenje slike (kontrast, smetnje),
 - evalvacija slike (veličine, oblika),
 - prepoznavanje obrazaca (pattern)
- *Kognitivna grafika*
 - ili “analiza scene” - identifikovanje i rad sa objektima fotografije ili kompjuterske slike (RTG film i elektronska kontura organa)

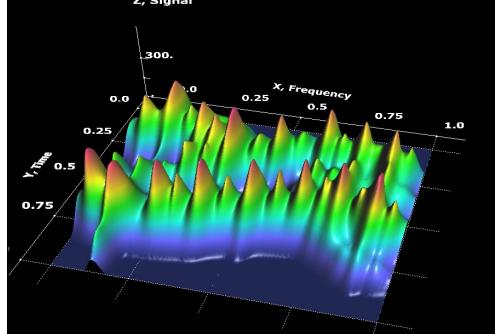
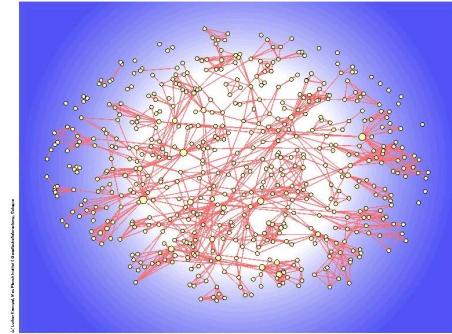
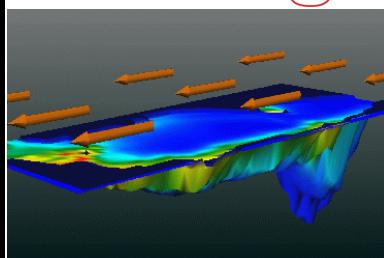
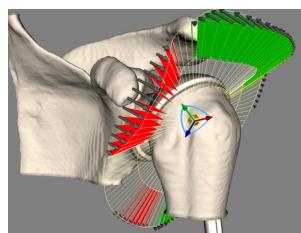
Real-Time (interaktivna) grafika Simulacije



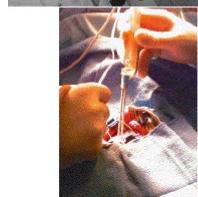
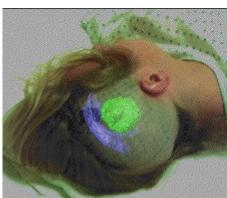
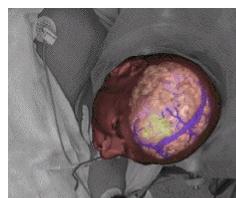
Real-Time (interaktivna) grafika CAD, CAA i CAM



Real-Time (interaktivna) vizuelizacija



Real-Time (interaktivna) grafika Virtuelna/augmentovana stvarnost

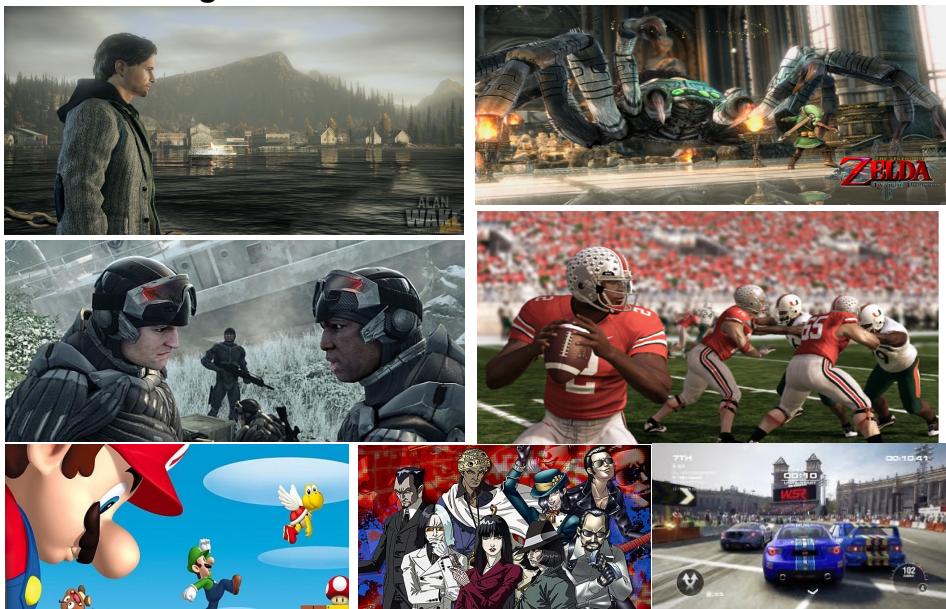


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Real-Time (interaktivna) grafika HCI i novi infromacioni prostori

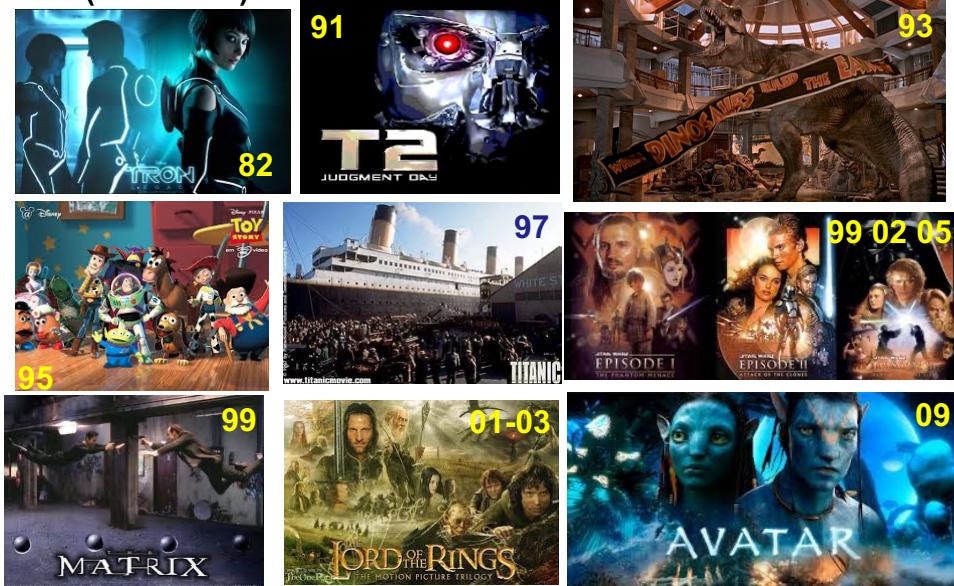


Real-Time (interaktivna) grafika Računarske igre



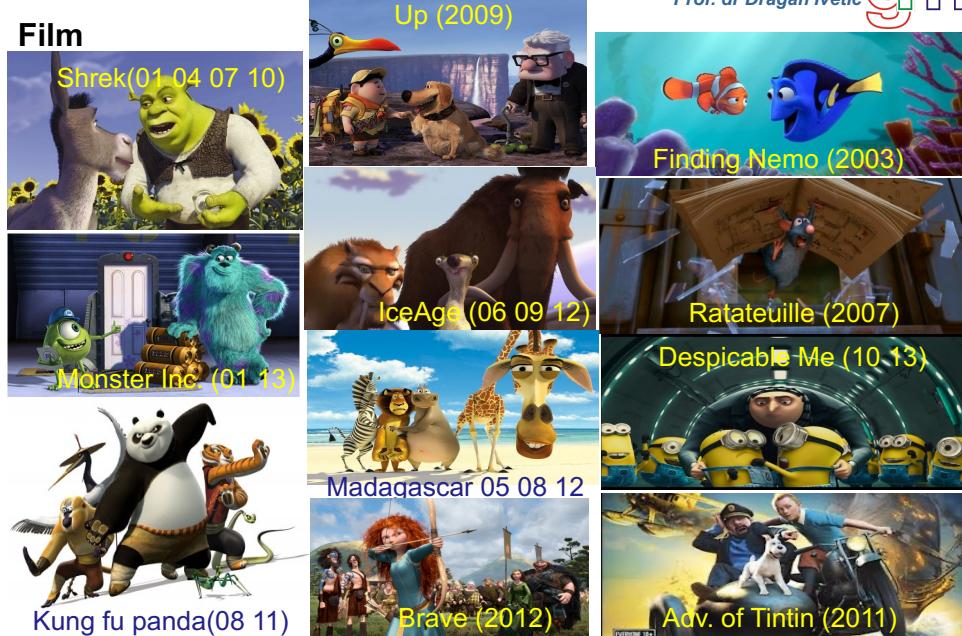
Non-Real-Time grafika

Film (umetnost)



Non-Real-Time grafika

Film



Non-Real-Time grafika

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Film



Non-Real-Time grafika

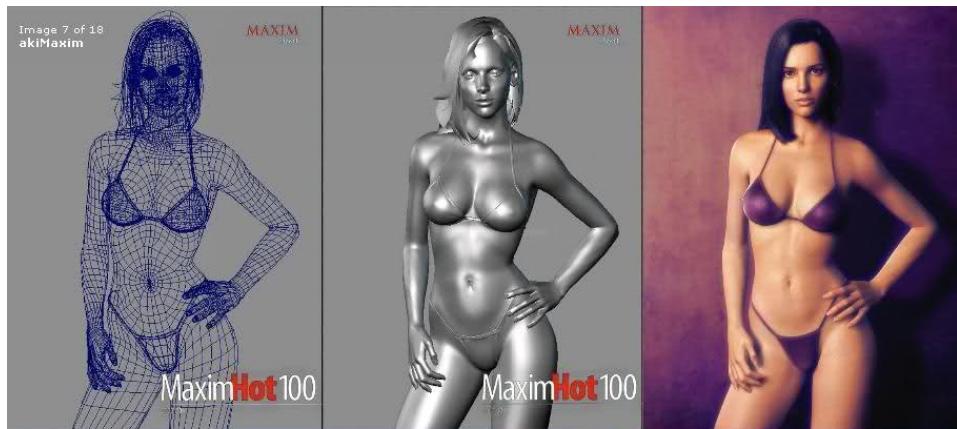
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Film



Non-Real-Time grafika Film

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Real-Time stiže non-Real-Time kvalitet?

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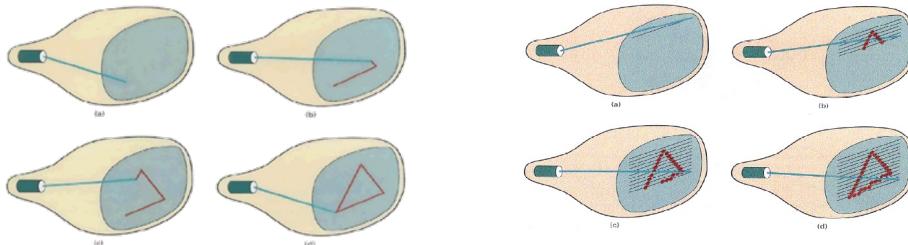


VEKTOR I/ILI TAČKA (raster) ...

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a može biti sprovedeno na nivou:

Softvera (logika) - i to na podnivou

instrukcije/komande, ili
podataka.

Hardvera (fizika).

... VEKTOR I/ILI TAČKA (raster) ...

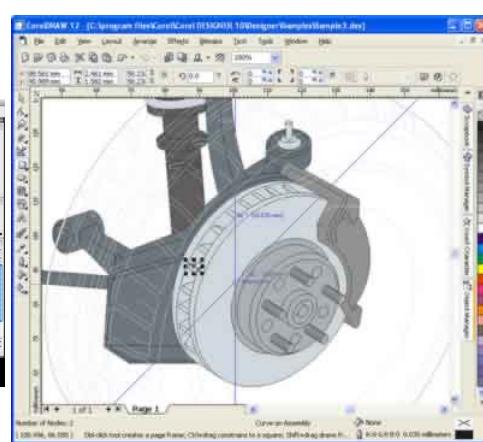
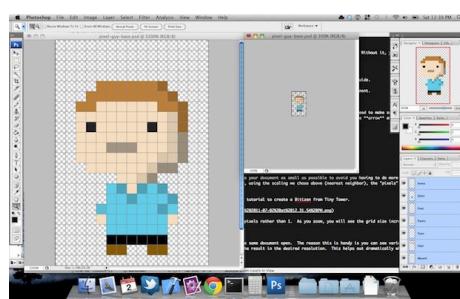
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Instrukciono logički (SW) – da li korisnik formira grafički prikaz angažujući komande nad tačkom (PhotoShop) ili vektorom (CorelDraw).



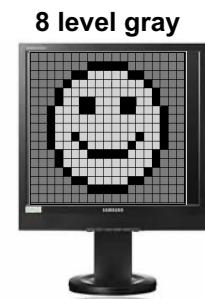
... VEKTOR I/ILI TAČKA (raster) ...

Data logic (File) – da li se komponovani grafički sadržaj trajno čuva kao skup tačaka (bmp, tiff, jpeg, raw, png, ...) ili vektora (cdr, svg, ai, ...).

Šta je sa *.wmf?

Koji fajl ide sa kojim SW?

Razmena?



```
222222222222222222
222222200000222222
222222005555500222
222205555555550222
222055555555555022
222055005550055022
222055500555005550
222055555555555550
222055555555555550
```

```
<?xml version="1.0" standalone="no"?>
<!DOCTYPE svg PUBLIC "-//W3C//DTD
SVG 1.1//EN"
"http://www.w3.org/Graphics/SVG/1.1/DTD/svg11.dtd">
<svg
xmlns="http://www.w3.org/2000/svg"
version="1.1">
<circle cx="100" cy="50" r="40"
stroke="black" stroke-width="2"
fill="red" />
</svg>
```

... VEKTOR I/ILI TAČKA (raster)

Fizički (HW) – kako se komponovani grafički sadržaj priprema za prikaz na ekranu prikaznog uređaja, kao skup vektora (vector HW) tačaka (raster HW).

Vektorski HW,

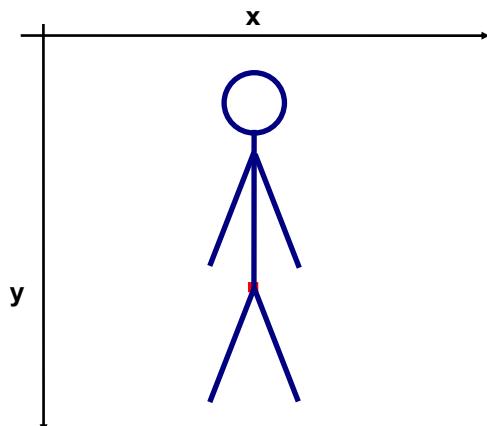
Rasterski HW se realizuje:

- bez GPU (deljena ili izolovana memorija),
- sa GPU (deljena ili izolovana memorija).

Koji format fajla je nativan za koji HW?

Komponovanje grafičkog prikaza

Dizajniramo

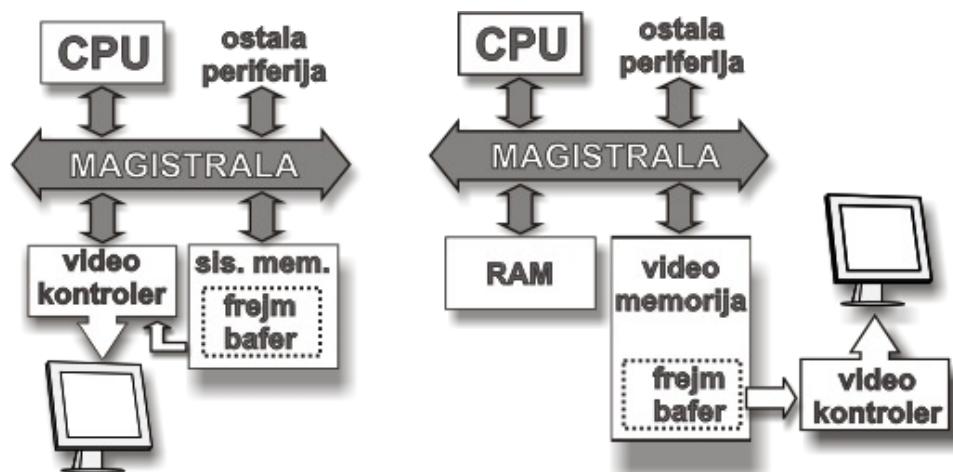


Programiramo

```
CrtajLiniju2D(x,y,x,y-24)
CrtajLiniju2D(x,y,x-6,y+17)
CrtajLiniju2D(x,y,x+6,y+17)
CrtajLiniju2D(x,y-20,x-6,y-7)
CrtajLiniju2D(x,y-20,x+6,y-7)

CrtajKrug2D(x,y-29,5)
```

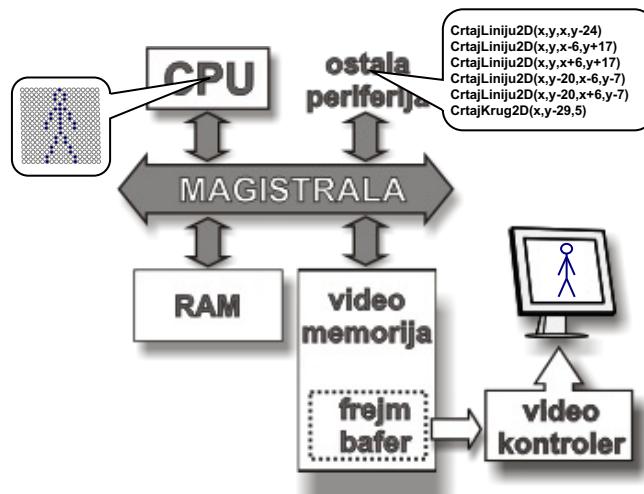
HW arhitektura rasterskog HW bez GPU



- Arhitektura sa deljenom memorijom.
- Arhitektura sa izolovanom memorijom.

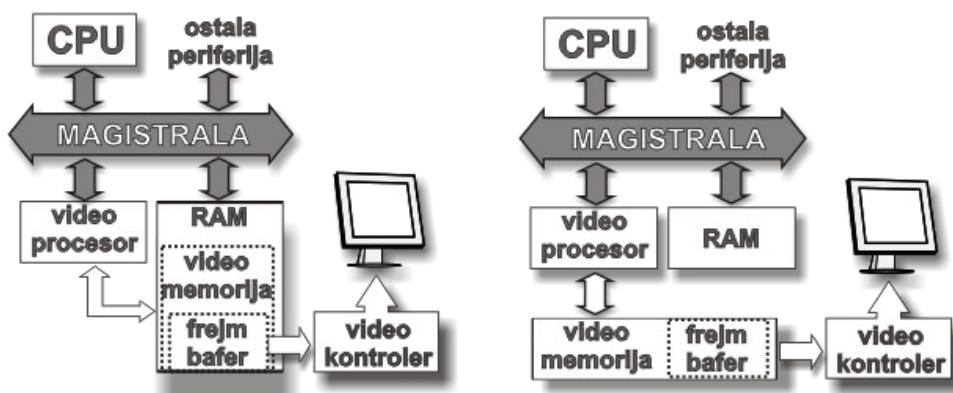
Tok aktivnosti prikaza na rasterskom HW bez GPU

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HW arhitektura rasterskog HW sa GPU

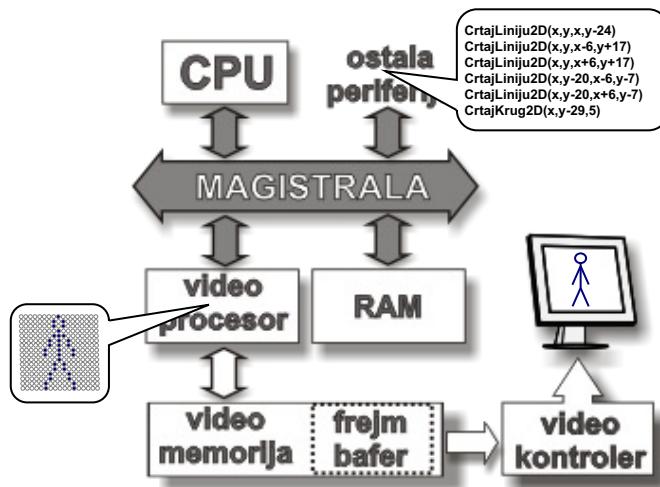
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- Arhitektura sa deljenom memorijom.
 - Arhitektura sa izolovanom memorijom.

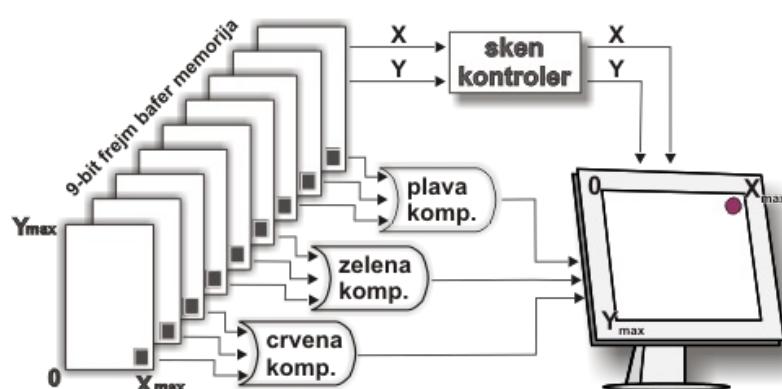
Tok aktivnosti prikaza na rasterskom HW sa GPU

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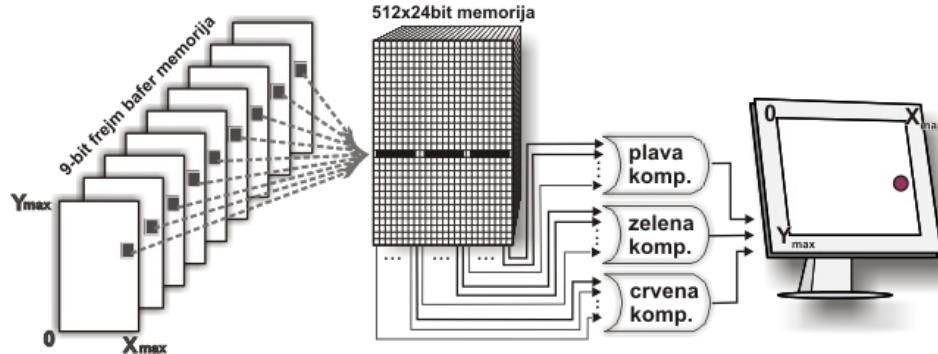
Video kontroler klasične arhitekture

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- za prikaz od **1024x1280** piksela i sa true-colour sistemom, **2^{24}** boja,
- veličina frejm bafra: **1.310.720 x 3** bajta = **3,75 Mbajta**.

Video kontroler LookUpTable arhitekture



- LUT – progr. sadržaj, 512 paleta od mogućih 2^{24} boja,
- Kolika je razlika u angažovanoj memoriji za prikaz od 1024×1280 piksela i sa 2^{24} boja, sa i bez LUT tabele?
- Koja arhitektura kontrolera je bolja? Zašto?
- Koji format grafičkog fajla odgovara ovom kontroleru?

Osnovni pojmovi i procesi

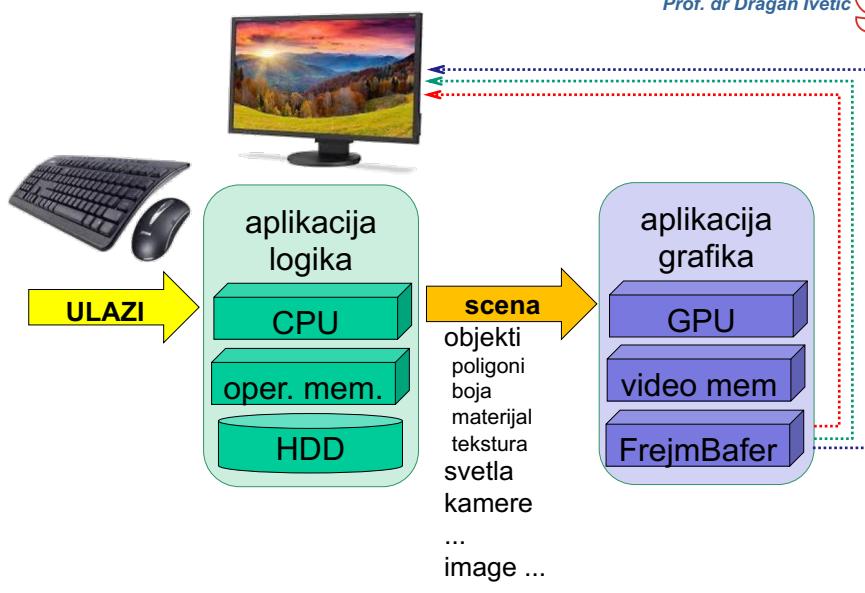


Samo 3D esencijalni i perceptivni:

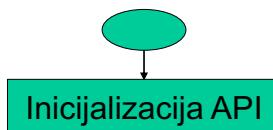
- Tačka, **vertex**, **vertices**
- Linija/linije, **edge**
- Trouglovi,
- Transformacije,
- 3D/2D projekcija/skrivanje.
- Kliping,
- Bojenje,
- Senčenje,
- Teksture,
- Spajanje.



Arhitektura grafičke aplikacije



Tok rada grafičke aplikacije

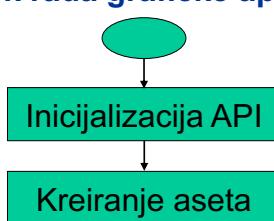


- kreiranje osnovnih struktura podataka za rad neke grafičke biblioteke:
 - OpenGL (OpenES, WebGL),
  
 - DirectX,

 - Vulkan,

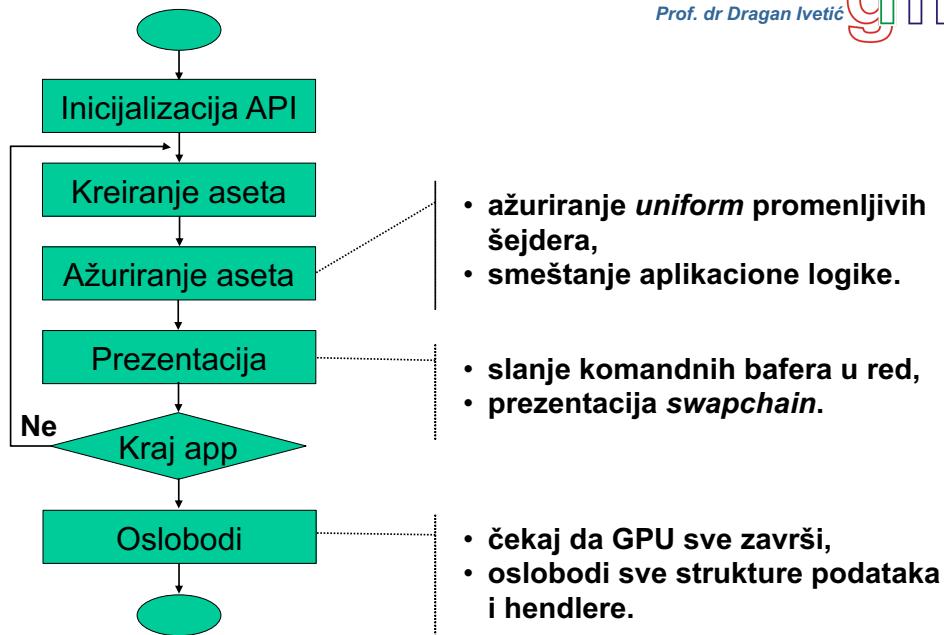
 - Metal,
 - ...

Tok rada grafičke aplikacije



- kreiranje struktura podataka za:
 - pokretanje šejdera,
 - ostalih procesa u grafičkom pajplajnu,
 - punjenje komandnog bafera GPU za izvršavanje,
 - slanje svih resursa u video memoriju GPU (deljenu ili izolovanu).

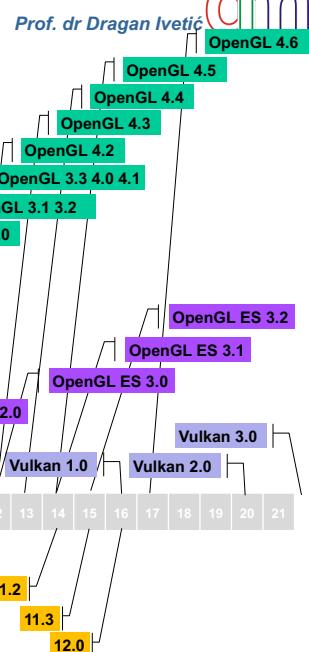
Tok rada grafičke aplikacije



Razvoj grafičkih API

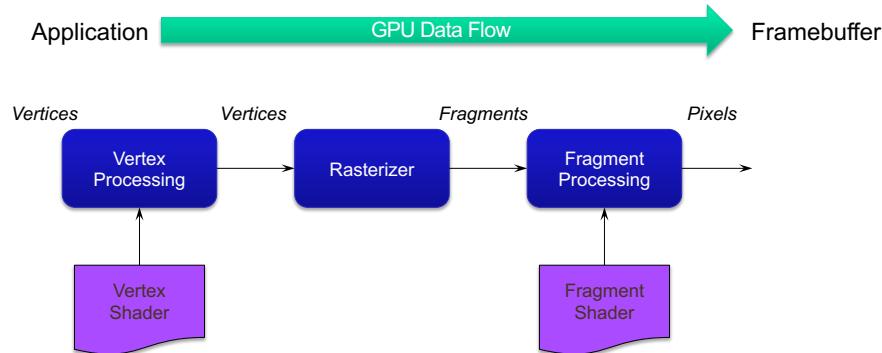
 Silicon Graphics, Inc.
razvio 80tih
Integrated Raster Imaging System Graphics Library

početkom 90. da formalizuju specifikaciju IRIS GL, nastao OpenGL kao industrijski standard kada SGI, DEC, IBM, Intel i Microsoft formiraju OpenGL Architecture Review Board



Grafički pajplajn ...

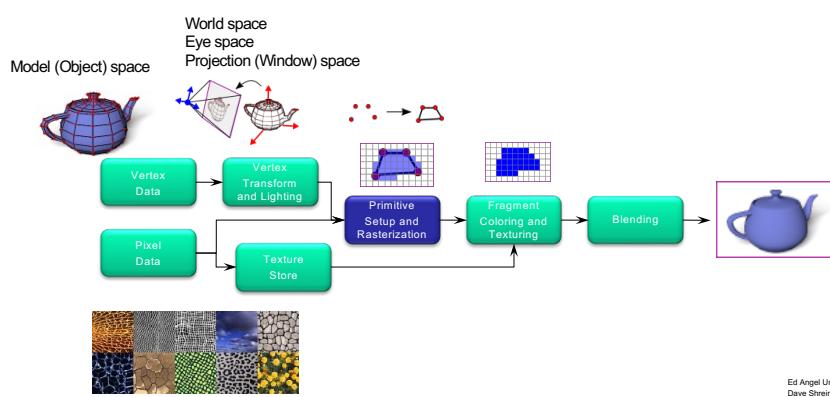
- opšti pajplajn.



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... Grafički pajplajn ...

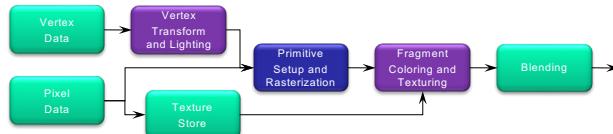
- OpenGL 1.0,
- pajplajn fiksne funkcije (implementirane funkcionalnosti izvršive u fiksiranom redosledu),
- moguće samo menjati attribute funkcije (koordinate, boju).



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... Grafički pajplajn ...

- OpenGL 2.0 proširuje obradu verteksa i fragmenata,
- oficijelno dodao šejdere (programčići koji GPU direktno izvršava),
- GLSL - OpenGL Shading Language,
- mada je i dalje fiksna funkcija dominirala.

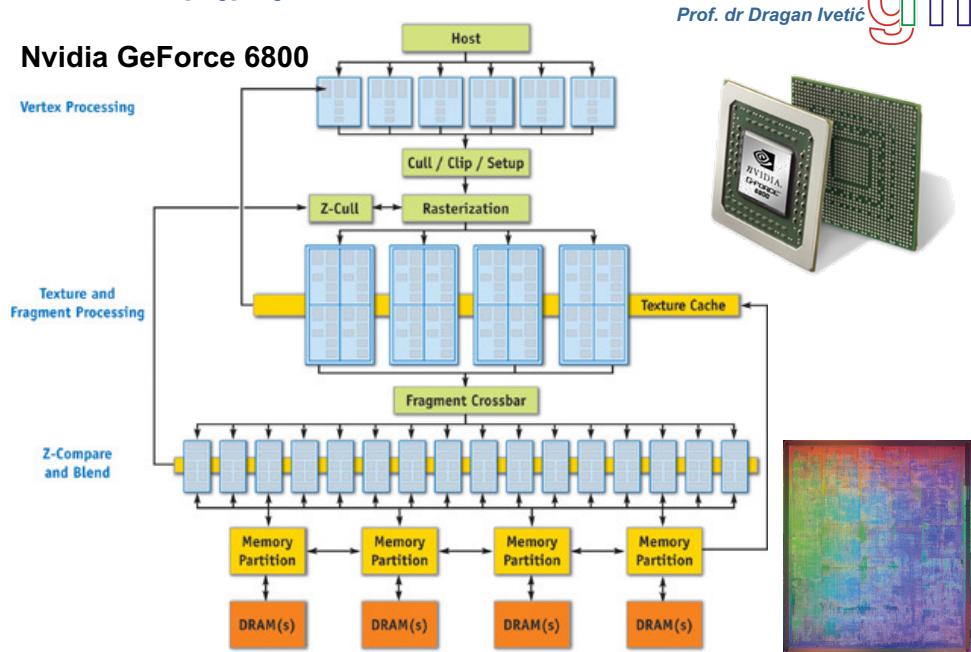


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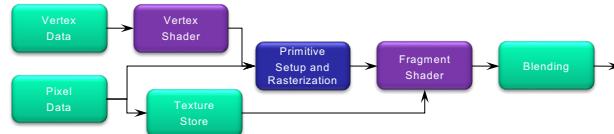
... Grafički pajplajn ...

Nvidia GeForce 6800



... Grafički pajplajn ...

- OpenGL 3.1 potpuno izbacuje fiksni deo,
- obavezna upotreba verteks i fragment šejdera,
- svi vertex podaci se šalju pomoću *buffer objects*.

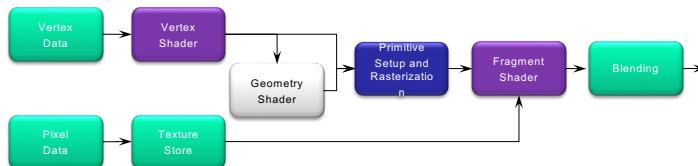


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... Grafički pajplajn ...

- OpenGL 3.2 uvodi šejder geometrije,
- postaje moguća promena geometrije u pajplajnu.



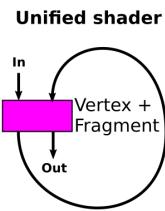
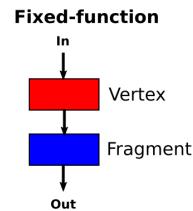
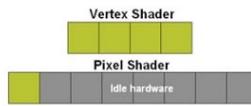
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... Grafički pajplajn ...

- OpenGL 3.3 podržava unified shader model GPU,

Why unify?

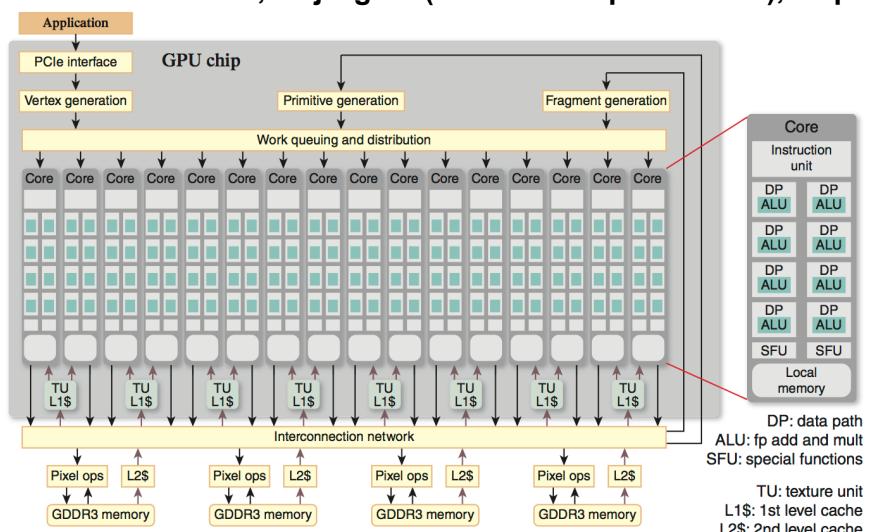


Why unify?



... Grafički pajplajn ...

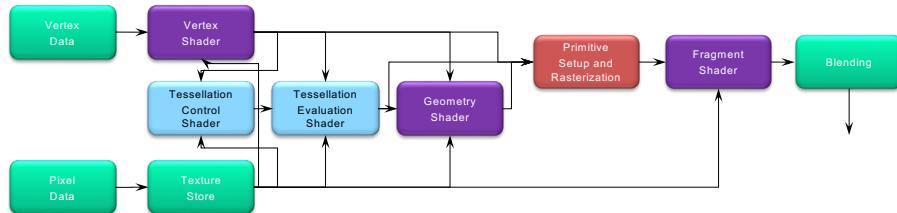
GeForce 9800 GTX, 16 jezgara (stream multiprocessors), 8 sp + sfu



Nvidia GTX280, 24 jezgara (8 unified stream proces.)

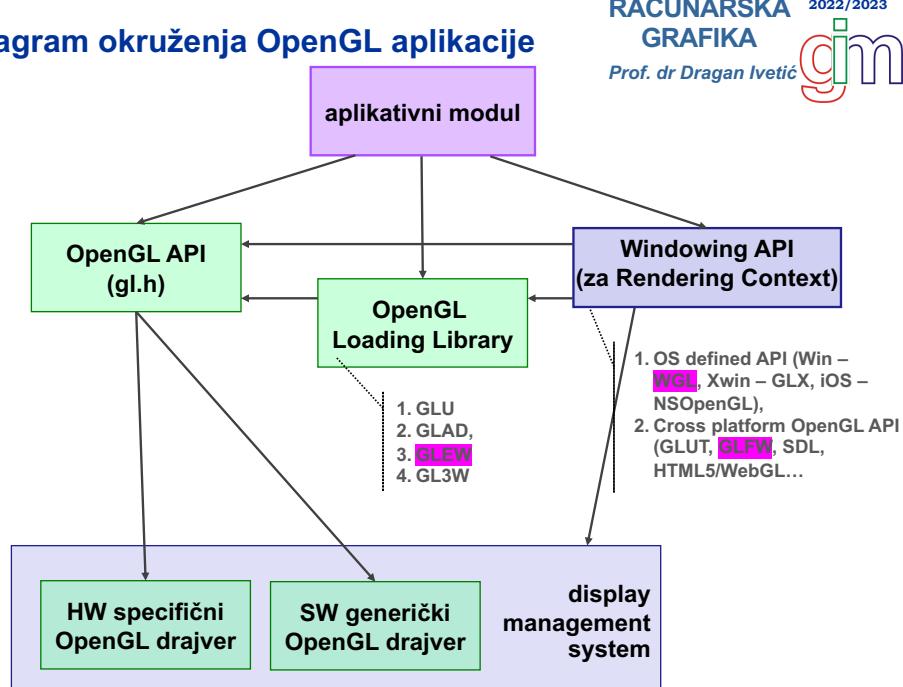
... Grafički pajplajn

- OpenGL 4.2 uvodi tesalacioni šejder,
- tesalacija se obavlja tandemskim radom dva šejdera – upravljački i evaluacioni.



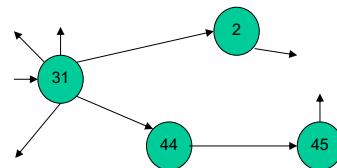
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Dijagram okruženja OpenGL aplikacije



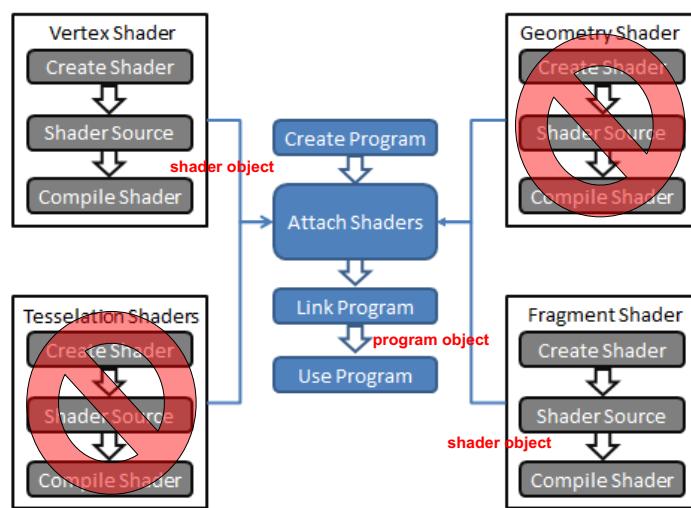
OpenGL je konačni automat

- stanje definisano skupom promenljivih (parametara) stanja
 - trenutna boja, veličina tačke i ostali atributi crtanja,
 - trenutne model&view transformacije,
 - trenutni model kamere i klippinga,
 - trenutni lighting&reflectance model,
 - trenutni viewport,...
- svaka promenljiva ima default vrednost koju zadržava dok je ne promenimo,
 - glColor3f(1.0, 0.0, 0.0), glPointSize(2.5), gluOrtho2D(...),...,
 - glEnable(...), glDisable(...),
- renderovanje prikaza se obavlja shodno vrednostima promenljivih trenutnog stanja OpenGL.



Nacrt strukture OpenGL programa ...

- koraci u kreiranju OpenGL programa,



... Nacrt strukture OpenGL programa ...

• izvršavanje:

- Vertex shader se izvršava za svaki verteks,
- Fragment shader se izvršava za svaki fragment,

• sadržaj:

- svaki shader mora imati main(),
- moguće klase promenljivih,
 - uniform – nema promena, read-only,
 - in – ulaz u shader, read-only,
 - out – izlaz (iz VS u FS, odnosno u frame bafer),

```
uniform mat4 projMatrix; // uniform input
in vec4 vertex; // attribut-input
out vec3 fragColor; // shader output
```

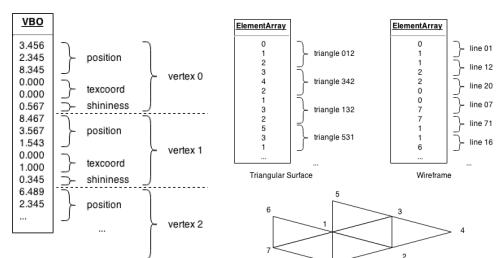
```
#version 330 core
layout(location = 0) in vec4 position;
void main()
{
    gl_Position = position;
}
```

```
#version 330 core
layout(location = 0) out vec4 color;
void main()
{
    color = vec4(1.0, 0.0, 0.0, 1.0);
}
```

... Nacrt strukture OpenGL programa ...

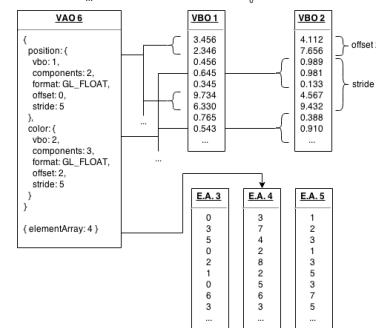
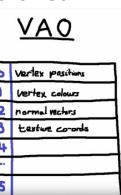
• vertex buffer objects (VBO):

- prenos podataka o verteksima u blokovima direktno u video memoriju,



• vertex array objects (VAO):

- niz do maksimalno 16 atributa o VBOs,
- opisuje stanje meš mreže objekta opisanih u referisanim VBO,

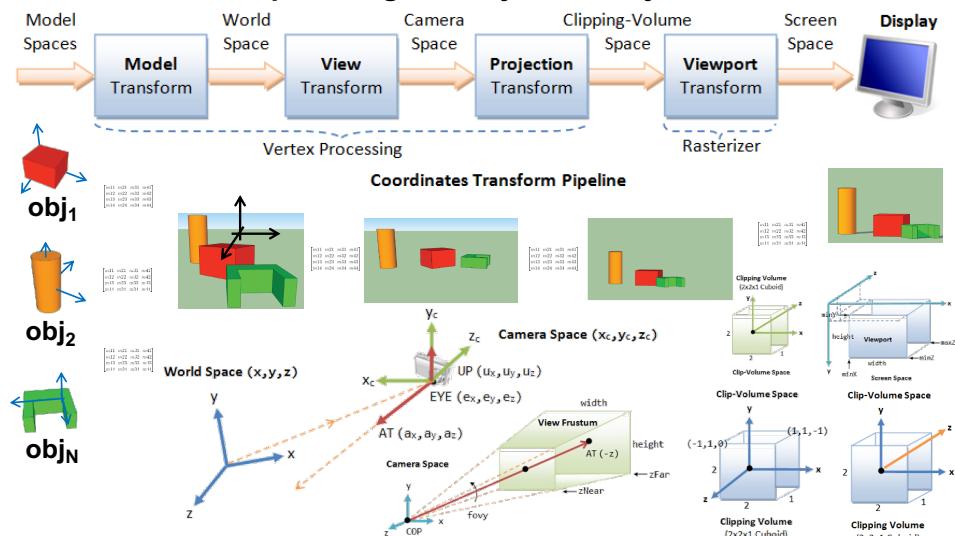


... Nacrt strukture OpenGL programa

- **opšti templejt OpenGL C programa**
 - #include datoteka (paziti na redosled),
 - deklaracije podataka i prototipova funkcija (barem za kreiranje i linkovanje šejdera),
 - **main ()**,
 - pokretanje GLFW za otvaranje prozora i hendlovanje dogadaja,
 - pokretanje GLEW biblioteke,
 - kreiranje buffer objekata i punjenje podacima,
 - kreiranje shader objekata i program objekta pomoću CreateShader,
 - kreiranje program objekta,
 - while (nije zatvoren prozor) {obriši prozor, glDrawArrays(...), glfwSwapBuffers(...)}
 - osloboди program objekat
 - **funkcija CompileShader ()**
 - otvara i prevodi shader kodne datoteke,
 - **funkcija CreateShader ()**
 - formira objekte programa i šejdera, poziva kompajliranje pa ih potom linkuje u jedan program objekat.
 - **ostale funkcije ...**
- **slično i C++, sem što su šejderi definisani globalno kao konstantni string.**

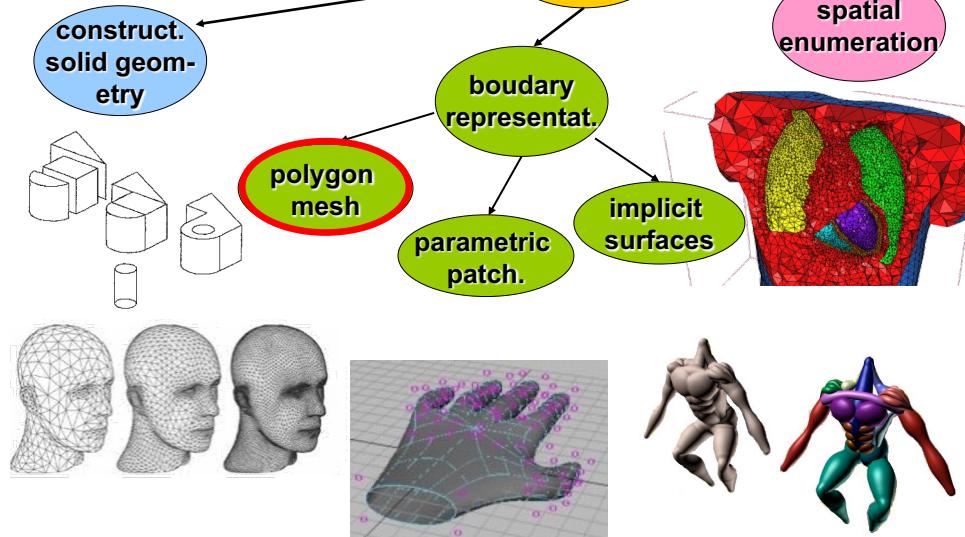
Modeli, prostori i transformacije

Kako načiniti 3D objekte/modele, pa ih staviti na 3D scenu, šetati se scenom i na 2D prikazu gledati njen sadržaj?



Modeli - 3D primitive

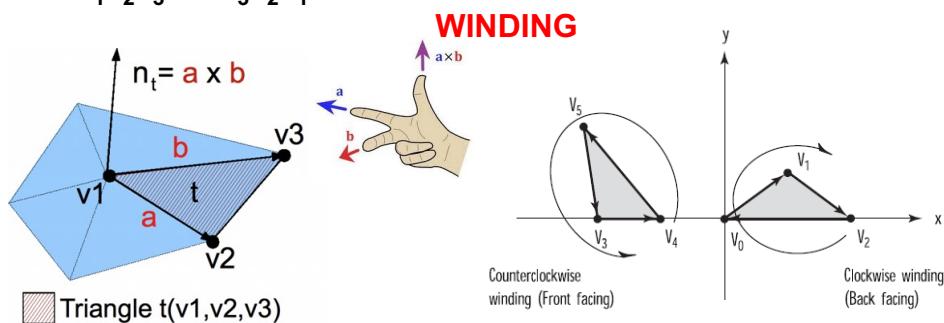
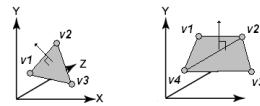
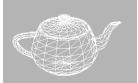
Kako načiniti 3D objekte/modele?



Modeli**Mreža poligona ...**

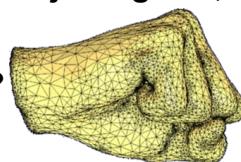
Skup ivica, temena i planarnih poligona spojenih tako da:

- svaka ivica je deljena među najviše dva susedna poligona,
- ivica povezuje dva temena,
- poligon je zatvorena sekvenca ivica.
- ima prednju i zadnju stranu,
 - $v_1v_2v_3 == v_3v_2v_1 ??$

**Modeli****... Mreža poligona ...**

Veća nepravilnost površine modela zahteva ? broj trouglova,

- kvalitet modela zavisi od broja trouglova,
- praviti modele sa najviše moguće trouglova?



50

500

2000

NE!

LOD zavisi od ...

Modeli

... Mreža poligona ...

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**LOD opada sa rastojanjem gledaoc-objekat!****Modeli**

... Mreža poligona ...

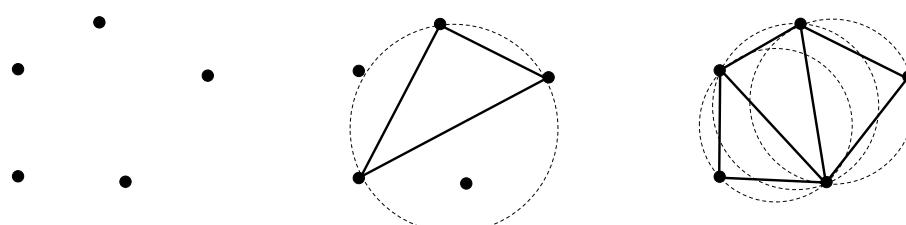
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**Kako da napravim 3D model objekta pomoću poligona sa odabranim LOD?****1. Generiše se skup tačaka koji pripadaju površini objekta:**

- ručno,**
- matematikom, ili**
- skeniranjem.**

2. Primeni se Delaunay-ova triangulacija.

Modeli

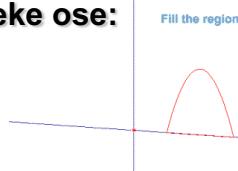
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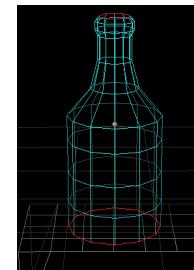
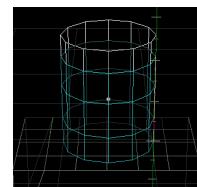
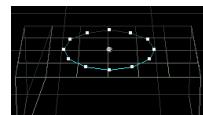
Prof. dr Dragan Ivetić

... Mreža poligona ...
matematikom ...**1. Tela koja se dobijaju vrtnjom krive oko neke ose:**

- sfera,
- cilindar,
- torus,
- konus...



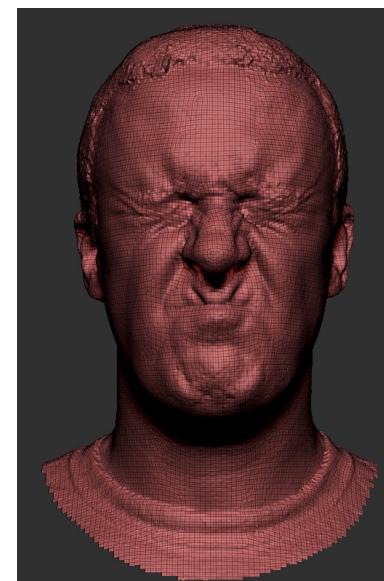
f(x) = Making a bundt cake.

2. Izvlačenjem (extrude) napolje/unutra novog elementa po nekoj krivoj bez gubljenja volumena.**Modeli**

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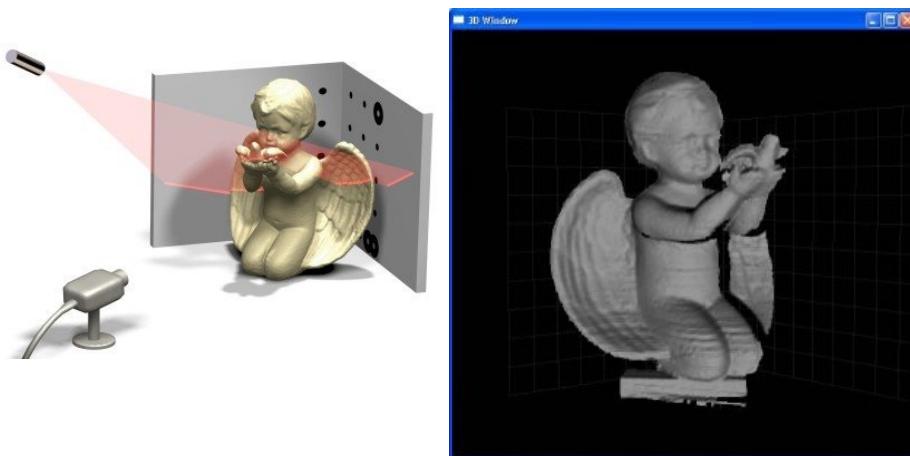
Prof. dr Dragan Ivetić

... Mreža poligona ...
skeniranjem...**1. 3D face capture - 18 kamera svaka sa 4.096x4.096 piksela u 1/10.000 s,**

Modeli

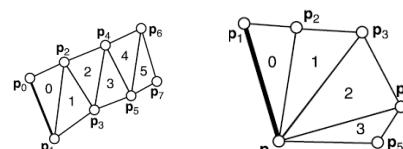
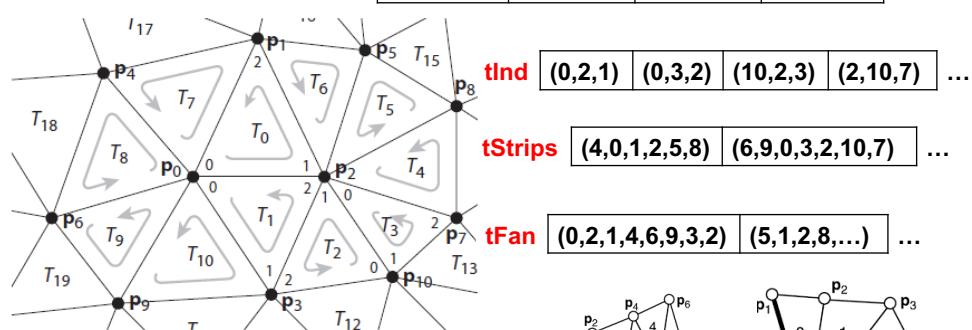
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... Mreža poligona ... Prof. dr Dragan Ivetić 
... skeniranjem

**2. lasersko 3D skeniranje,
DAVID-Laserscanner 2.6.1 - Portable,**

**Modeli**

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... Mreža poligona ... Prof. dr Dragan Ivetić 

Kako definisati trouglove mreže na (skladišno i procesno) efikasan način? **verts** (x_0,y_0,z_0) (x_1,y_1,z_1) (x_2,y_2,z_2) (x_3,y_3,z_3) ...

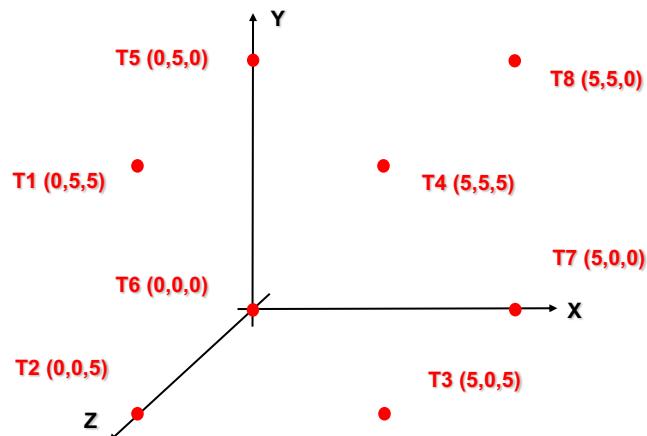
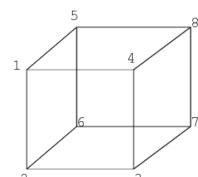


Osnovne definicije trouglova:

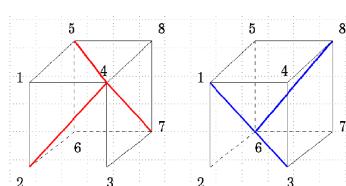
1. liste (list),
2. trake (strips), **Konzistentnost orientacije trouglova?**
3. ventilatori (fan).

Modeli**... Mreža poligona**

Predstaviti temena pomoću liste, ventilatora i trake.

**Modeli****... Mreža poligona****trouglovi:**

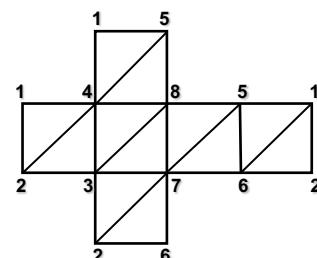
T241, T234, T384, T378, T758, T765,
T615, T625, T451, T485, T273 i T267.

**Fan**

- 4 1 2 3 7 8 5 1
- 6 2 1 5 8 7 3 2

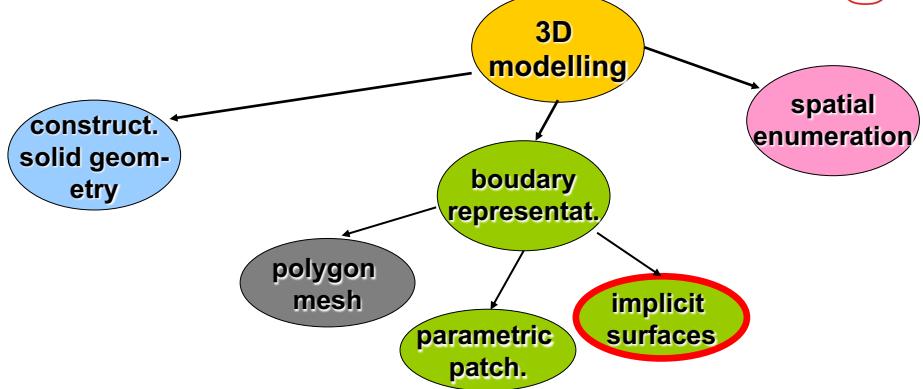
Strips

- 1 2 4 3 8 7 5 6 1 2
- 1 4 5 8
- 2 3 6 7



Modeli

Implicitne površine ...



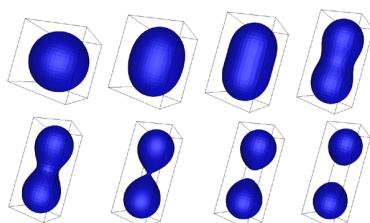
Definisanje isopovršina oslanjajući se na implicitnu definiciju lopte

$$x^2 + y^2 + z^2 = r^2$$

Kako bi nacrtali loptu za $r = 34$ sa centrom u (a, b, c) ?

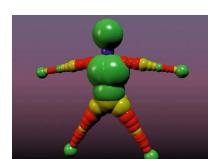
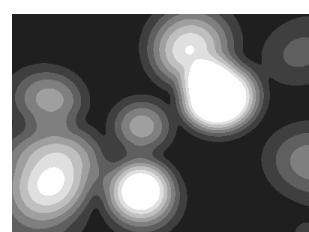
Modeli

... Implicitne površine ...



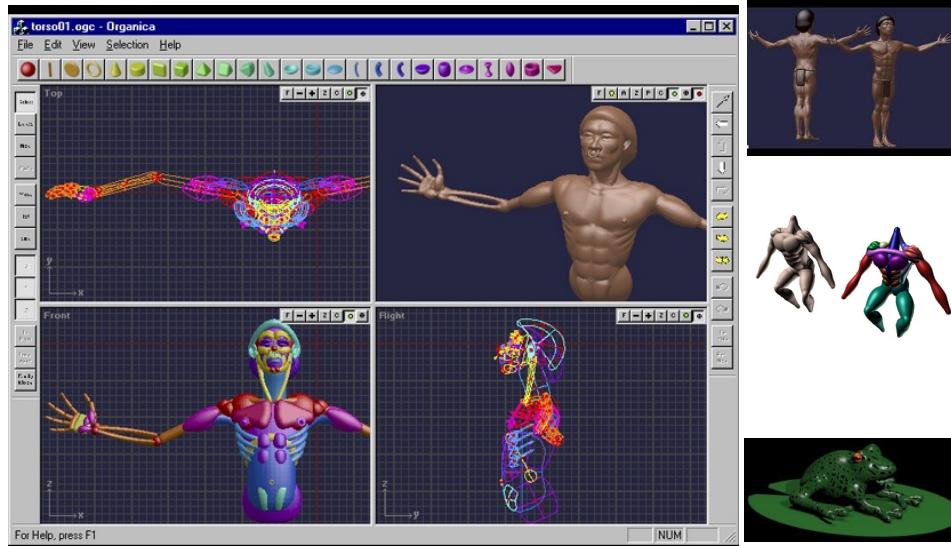
Metaballs (blobby objects) - čestična tela radijalne gustine čiju površinu čine čestice gustine određenog praga!

$$\sum_{i=1}^N \text{metaballs}_i(x, y, z) \leq PRAG$$



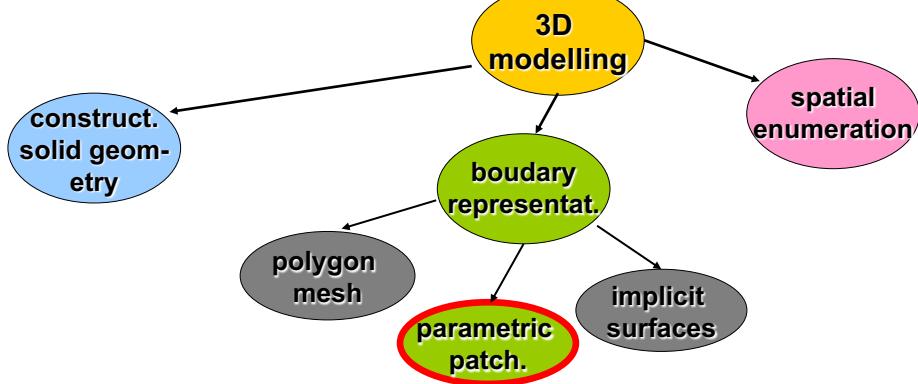
Modeli**... Implicitne površine ...**

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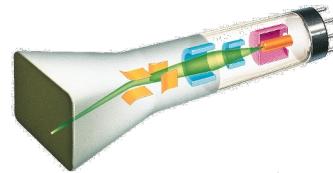
Programsko okruženje Organica**Modeli****... Implicitne površine**

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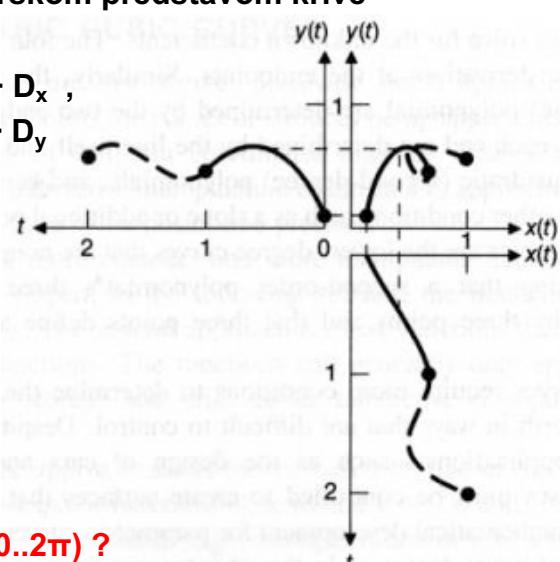
Modeli

Da li crtati 2D krivu eksplisitno
 $y = A x^3 + B x^2 + C x + D$
 i to krivu u obliku petlje?

**Modeli**

Jednostavnije parametarskom predstavom krive

$$\begin{aligned} x(t) &= A_x t^3 + B_x t^2 + C_x t + D_x , \\ y(t) &= A_y t^3 + B_y t^2 + C_y t + D_y \end{aligned}$$

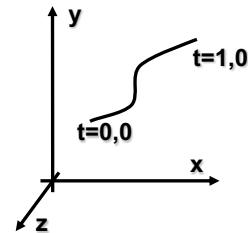


Šta će se prikazati za
 $(x,y) = (\cos t, \sin t) , t \in (0..2\pi) ?$

Modeli**... Parametarske zakepte ...**

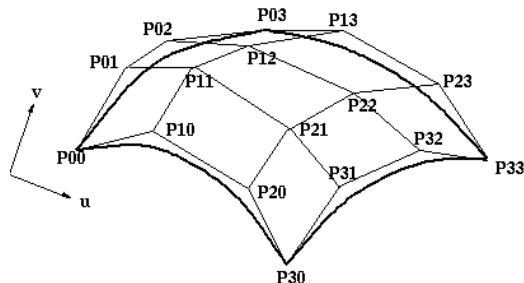
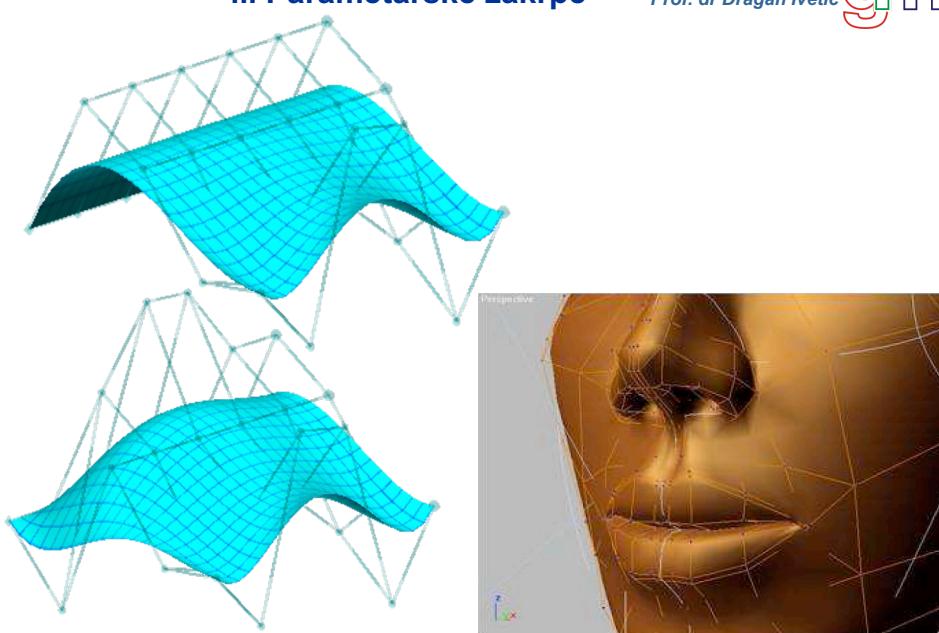
Šta bi bilo formirano sa

$$\begin{aligned}x(t) &= A_x t^3 + B_x t^2 + C_x t + D_x , \\y(t) &= A_y t^3 + B_y t^2 + C_y t + D_y , \\z(t) &= A_z t^3 + B_z t^2 + C_z t + D_z .\end{aligned}$$



Šta bi bilo formirano sa

$$x(u,v), y(u,v), z(u,v) .$$

**Modeli****... Parametarske zakepte ...**

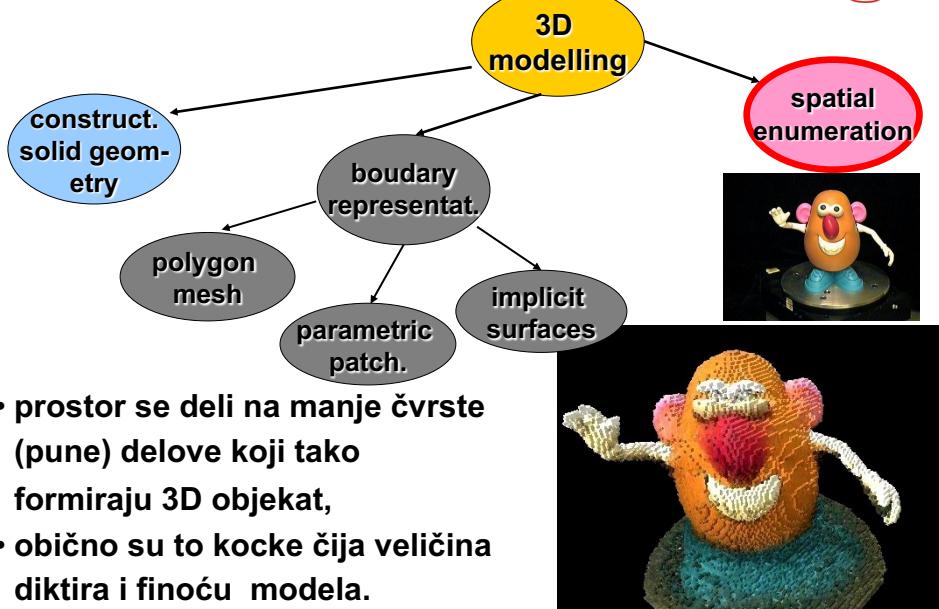
Modeli

Prostorna enumeracija ...

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Modeli

... Prostorna enumeracija ...

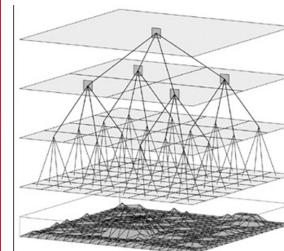
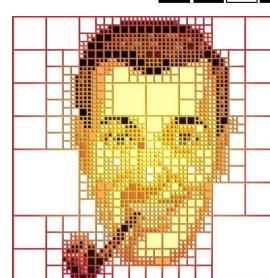
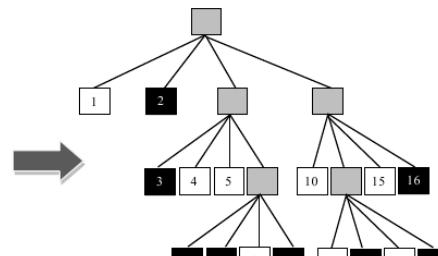
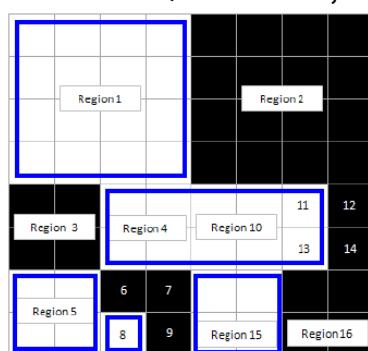
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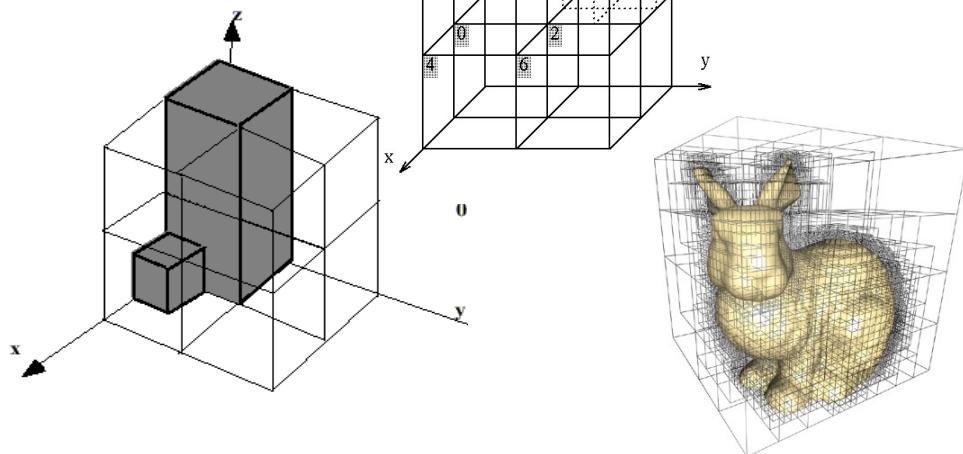
- za 2D - QUADTREE,



Modeli

... Prostorna enumeracija

- za 3D - OCTREE,
voxels,



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Iur Dragan Ivetić



Modeli

Modelovanje punim telom ...

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Prof. dr Dragan Ivetić



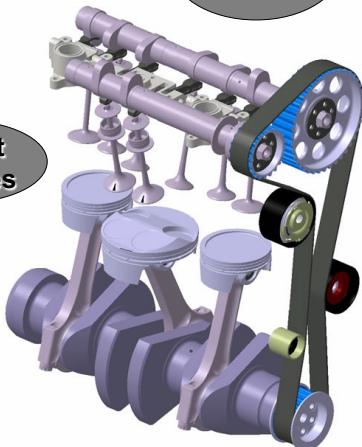
**construct.
solid geom-
etry**

**3D
modelling**

**spatial
enumeration**

**boundary
representat.**

**parametric
patch.**

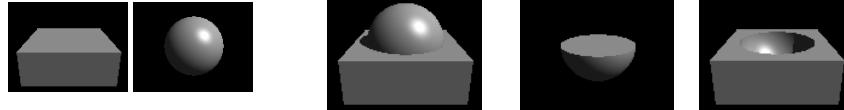


- solid modeling - kreirali za CAD,



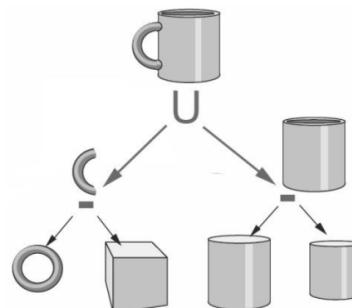
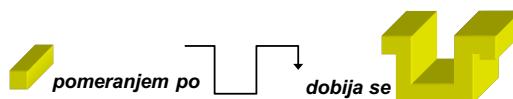
Modeli**... Modelovanje punim telom ...**

- solid modeling - kreirali za CAD,
- operacija skupova (U , ∩ , /)



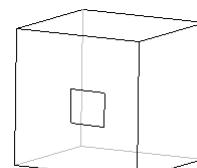
nad primitivama (geometrijska tela),

- sweep.

**Modeli****... Modelovanje punim telom ...**

- posle su dodali nove funkcije modelovanja ...

Solid Extrusion – obično za kreiranje osnovnih modela za nove gradnje.



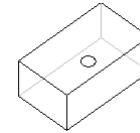
Cut/Slot Extrusion – obično za otvore, rupe, ključaonice, polaze, žljebove i sl.



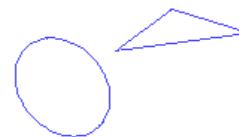
Revolved Extrusion – obično za osnovne modele, cevi, torusne oblike, rebara i sl.

Modeli**... Modelovanje punim telom**

Revolved Cut – obično za unutrašnje cevi, odlivci, hlađenje SUS motora.



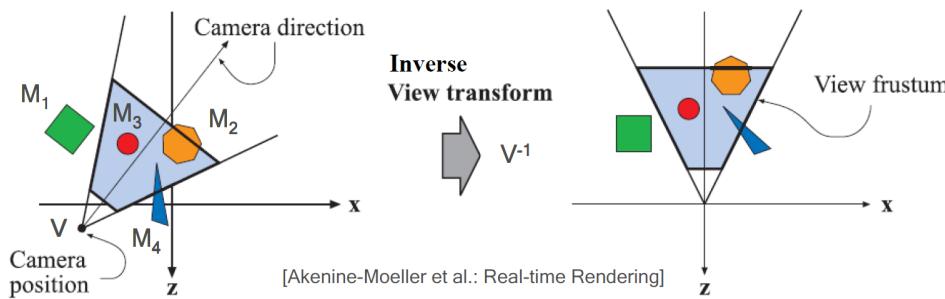
Loft – obično za nove osnovne oblike sa topološki sličnim terminalima.



Shell – obično za šolje, činije, stvari sa tankim okvirom/zidom.

**3D transformacije****Zašto ...**

- da pozicioniramo, preoblikujemo i animiramo objekte, svetla i virtuelnu kameru u 3D prostoru,



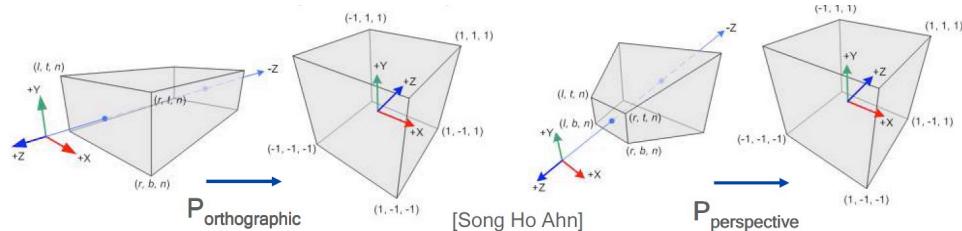
- M_i i V su 4×4 matrice 3D transformacija,
- M_1, M_2, M_3 i M_4 pozicioniraju objekte a V kameru na scenu,
- pa V^{-1} sve pomera u koordinatni početak uz $-Z$ osu,
- tj., na objekat i sprovodi modelview transformaciju $V^{-1}M_i$.

3D transformacije

... Zašto

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- da ortografski ili perspektivno projektujemo 3D geometriju na ravan,



- matrica P transformiše view volume (kuboid ili frustum) na kanonski view volume (unit cube),
 - transformacija se primjenjuje i na temena i na normale,
 - temena i normale se predstavljaju 4D vektorima.

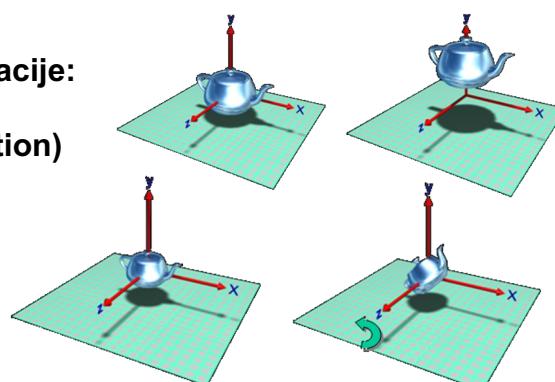
3D transformacije

Elementarne transformacije ...

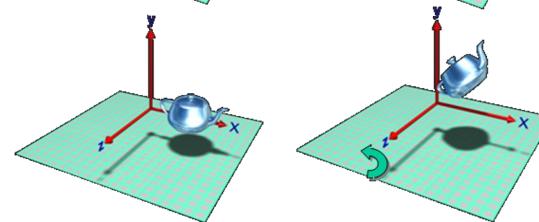
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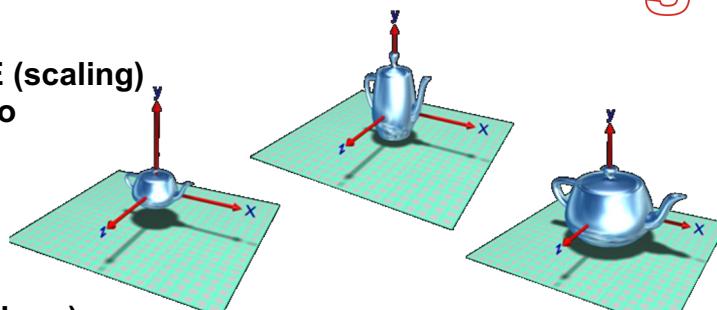
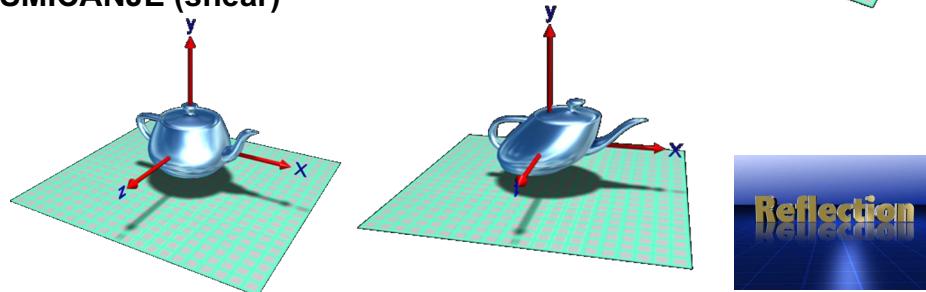
Elementarne transformacije:

TRANSLACIJA (translation)



ROTACIJA (rotation)



3D transformacije**... Elementarne transformacije****SKALIRANJE (scaling)
(ne)uniformno****SMICANJE (shear)****3D transformacije****Primeri u 2D ...****2D TRANSLACIJA**

$$\begin{bmatrix} x_t \\ y_t \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} x_{pomeraj} \\ y_{pomeraj} \end{bmatrix}$$

**2D SKALIRANJE**

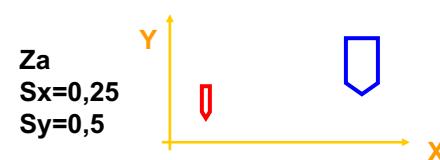
$$\begin{bmatrix} x_t \\ y_t \end{bmatrix} = \begin{bmatrix} S_x & 0 \\ 0 & S_y \end{bmatrix} * \begin{bmatrix} x \\ y \end{bmatrix}$$

Uniformno , $S_x=S_y$

- $S_x, S_y > 1$, veće i dalje od $(0,0)$,
- $S_x, S_y < 1$, manje i bliže

Neuniformno, $S_x \neq S_y$

- $S_x, S_y > 1$, veće i dalje od $(0,0)$,
- $S_x, S_y < 1$, manje i bliže

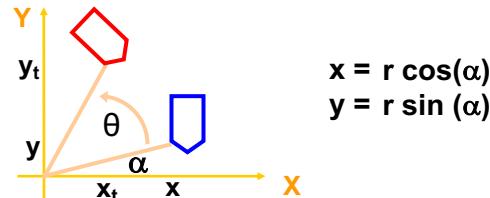


3D transformacije**... Primeri u 2D ...**

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**2D ROTACIJA**

$$\begin{bmatrix} x_t \\ y_t \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} * \begin{bmatrix} x \\ y \end{bmatrix}$$

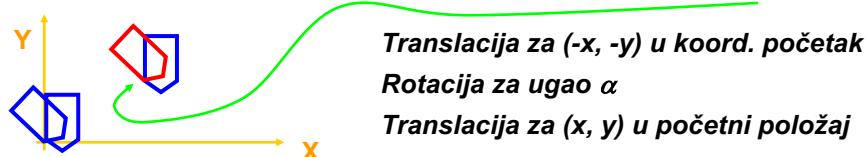
Kako rotirati 2D objekat za ugao α oko njegovog temena na koordinatama (x, y) ?

3D transformacije**... Primeri u 2D**

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**Rotiranje 2D objekta za ugao α oko temena (x, y)**

$$\begin{bmatrix} x_t \\ y_t \end{bmatrix} = \begin{bmatrix} x_{pom} \\ y_{pom} \end{bmatrix} + \left(\begin{bmatrix} \cos(\alpha) & -\sin(\alpha) \\ \sin(\alpha) & \cos(\alpha) \end{bmatrix} * \left(\begin{bmatrix} -x_{pom} \\ -y_{pom} \end{bmatrix} + \begin{bmatrix} x \\ y \end{bmatrix} \right) \right)$$

Dosta nesretno rešenje u pogledu efikasnosti!

Zašto?

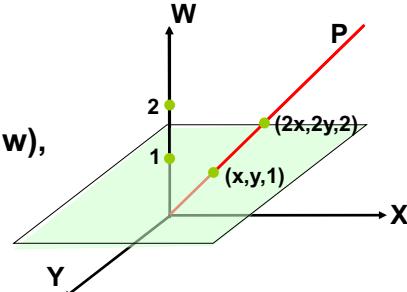
Kome i kako pomoći da se dobije na efikasnosti?

3D transformacije

Homogenizacija

HOMOGENE KOORDINATE, zakomplikujemo da bi postalo sve jednostavnije:

- 1D - tačka (x) postaje (x, w),
- 2D - tačka (x, y) postaje (x, y, w),
- 3D - tačka (x, y, z) postaje (x, y, z, w),
-
- **gde je uvek $w \geq 1$!!**
- **u RG je $w = 1$ za tačku,**



$$(x, y, 1) \equiv (2x, 2y, 2) \equiv (3x, 3y, 3) \equiv \dots \equiv (nx, ny, n)$$

Kako iz Homogenih (a, b, w) u Dekartove koordinate?

Za $w \rightarrow 0$, x i y koordinate $\rightarrow \infty$.

Koordinata ($x, y, 0$) je tačka u beskonačnosti,
u RG se naziva vektorom u pravcu (x, y).

3D transformacije

Homog. 2D trans. ...

2D TRANSLACIJA

$$\begin{bmatrix} x_t \\ y_t \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & x_{pomeraj} \\ 0 & 1 & y_{pomeraj} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

2D SKALIRANJE

$$\begin{bmatrix} x_t \\ y_t \\ 1 \end{bmatrix} = \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

2D ROTACIJA

$$\begin{bmatrix} x_t \\ y_t \\ 1 \end{bmatrix} = \begin{bmatrix} \cos(\alpha) & -\sin(\alpha) & 0 \\ \sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

2D SMICANJE

$$\begin{bmatrix} x_t \\ y_t \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & S_{saY} & 0 \\ S_{sax} & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

2D REFLEKSIJA oko ose koja zaklapa ugao θ sa x osom

$$\begin{bmatrix} x_t \\ y_t \\ 1 \end{bmatrix} = \begin{bmatrix} \cos(2\theta) & \sin(2\theta) & 0 \\ \sin(2\theta) & -\cos(2\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

3D transformacije

... Homog. 2D trans.

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Rotiranje 2D objekta za ugao α oko temena (x, y)

$$\begin{bmatrix} x_t \\ y_t \end{bmatrix} = \begin{bmatrix} x_{pom} \\ y_{pom} \end{bmatrix} + \left(\begin{bmatrix} \cos(\alpha) & -\sin(\alpha) \\ \sin(\alpha) & \cos(\alpha) \end{bmatrix} * \left(\begin{bmatrix} -x_{pom} \\ -y_{pom} \end{bmatrix} + \begin{bmatrix} x \\ y \end{bmatrix} \right) \right)$$

$$\begin{bmatrix} x_t \\ y_t \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & x_{pomeraj} \\ 0 & 1 & y_{pomeraj} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(\alpha) & -\sin(\alpha) & 0 \\ \sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & -x_{pomeraj} \\ 0 & 1 & -y_{pomeraj} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} x_t \\ y_t \\ 1 \end{bmatrix} = \begin{bmatrix} \cos(\alpha) & -\sin(\alpha) & x_{pomeraj}(1-\cos(\alpha)) + y_{pomeraj}\sin(\alpha) \\ \sin(\alpha) & \cos(\alpha) & y_{pomeraj}(1-\cos(\alpha)) - x_{pomeraj}\sin(\alpha) \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

3D transformacije

Homog. 3D trans. ...

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3D TRANSLACIJA

$$\begin{bmatrix} x_t \\ y_t \\ z_t \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & x_{pomeraj} \\ 0 & 1 & 0 & y_{pomeraj} \\ 0 & 0 & 1 & z_{pomeraj} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

3D SKALIRANJE

$$\begin{bmatrix} x_t \\ y_t \\ z_t \\ 1 \end{bmatrix} = \begin{bmatrix} S_x & 0 & 0 & 0 \\ 0 & S_y & 0 & 0 \\ 0 & 0 & S_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

3D SMICANJE

$$\begin{bmatrix} x_t \\ y_t \\ z_t \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & S_{XsaY} & S_{XsaZ} & 0 \\ S_{YsaX} & 1 & S_{YsaZ} & 0 \\ S_{ZsaX} & S_{ZsaY} & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Kako bi izgledale matrice inverzne transformacije?

3D REFLEKSIJA po ravnima $x=0, y=0$ i $z=0$

$$\begin{bmatrix} x_t \\ y_t \\ z_t \\ 1 \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

3D transformacije

... Homog. 3D trans. ...

3D ROTACIJA po svakoj od osa

$$\begin{bmatrix} x_t \\ y_t \\ z_t \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) & 0 \\ 0 & \sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} x_t \\ y_t \\ z_t \\ 1 \end{bmatrix} = \begin{bmatrix} \cos(\alpha) & 0 & \sin(\alpha) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(\alpha) & 0 & \cos(\alpha) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} x_t \\ y_t \\ z_t \\ 1 \end{bmatrix} = \begin{bmatrix} \cos(\alpha) & -\sin(\alpha) & 0 & 0 \\ \sin(\alpha) & \cos(\alpha) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

komutativnost?

3D transformacije

... Homog. 3D trans.

Doprinos homogenih koordinata -
homogenizacija matrice transformacija

$$\begin{bmatrix} m_{00} & m_{01} & m_{02} & t_0 \\ m_{10} & m_{11} & m_{12} & t_1 \\ m_{20} & m_{21} & m_{22} & t_2 \\ p_0 & p_1 & p_2 & w \end{bmatrix}$$

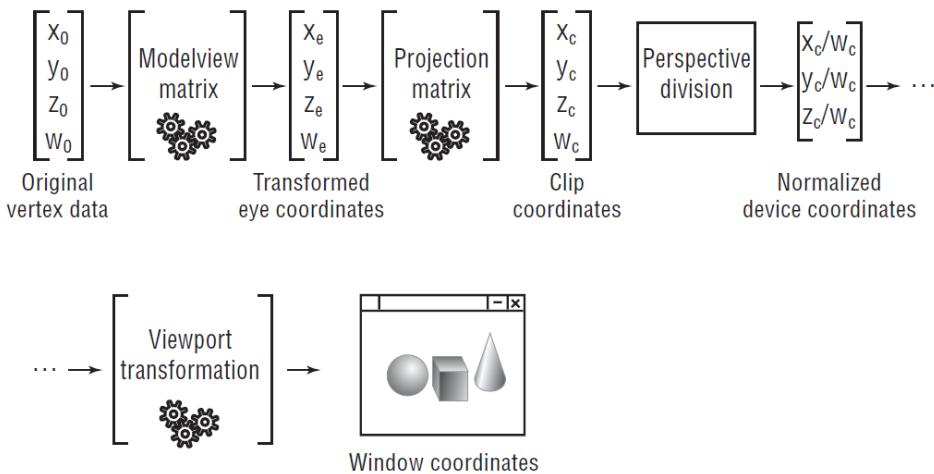
pri čemu su

 m_{ii} t_i p_i w

3D transformacije

Pajplajn transformacija temena

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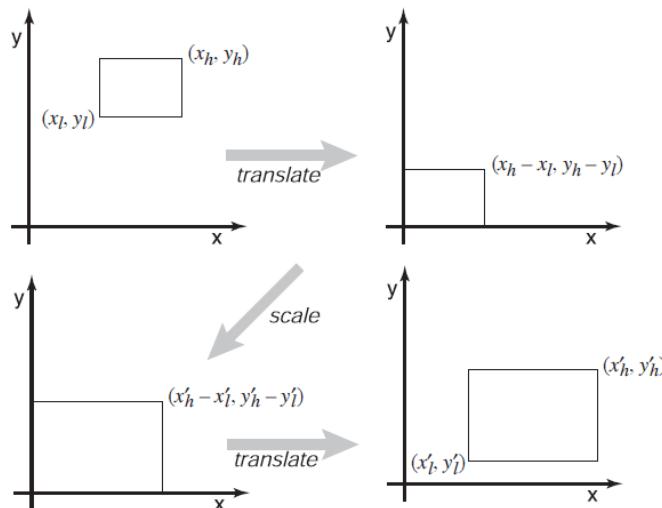


3D transformacije

Transformacija prozora ...

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Kreirati matricu koja bi tačke iz jednog pravougaonika $[x_l, x_h] \times [y_l, y_h]$ u drugi pravougaonik $[x'_l, x'_h] \times [y'_l, y'_h]$!



3D transformacije

... Transformacija prozora ...

$$M = T_{x'_l, y'_l} \times S \times T_{-x_l, -y_l} =$$

$$= \begin{bmatrix} 1 & 0 & x'_l \\ 0 & 1 & y'_l \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} \frac{x'_h - x'_l}{x_h - x_l} & 0 & 0 \\ 0 & \frac{y'_h - y'_l}{y_h - y_l} & 0 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & -x_l \\ 0 & 1 & -y_l \\ 0 & 0 & 1 \end{bmatrix} =$$

$$= \begin{bmatrix} \frac{x'_h - x'_l}{x_h - x_l} & 0 & \frac{x'_l x_h - x'_h x_l}{x_h - x_l} \\ 0 & \frac{y'_h - y'_l}{y_h - y_l} & \frac{y'_l y_h - y'_h y_l}{y_h - y_l} \\ 0 & 0 & 1 \end{bmatrix}$$

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Kako bi izgledalo za
matricu
transformacije
tačaka jednog
kuboida u drugi?

3D transformacije

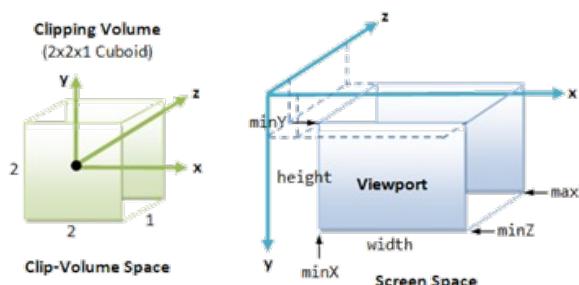
... Transformacija prozora

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Kreirana matrica je Viewport transformacija!



$$M = \begin{bmatrix} \frac{width}{2} & 0 & \min X + \frac{width}{2} \\ 0 & \frac{height}{2} & \min Y + \frac{length}{2} \\ 0 & 0 & 1 \end{bmatrix}$$

Kako deo 3D prostora prikazati na 2D?

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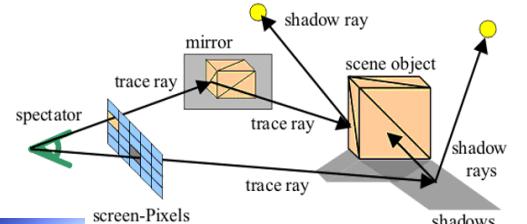
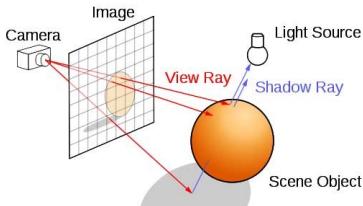
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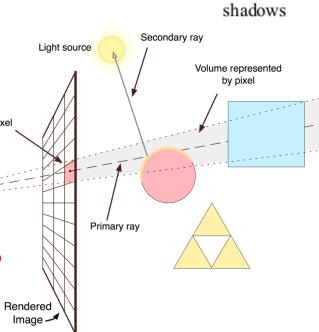


Moguće su dve strategije 3D na 2D:

1. Raytracing algoritmima – non-real-time grafika?



Problemi?

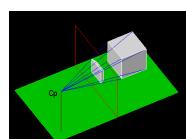


Moguća orto. projekcija?

Kako ubrzati? Kako utiče na pajplajn?

2. Matricama projekcione transformacije

PROJEKCIJA



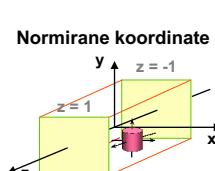
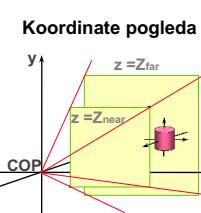
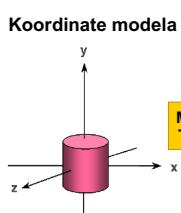
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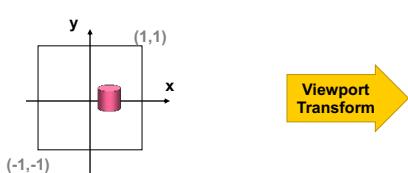
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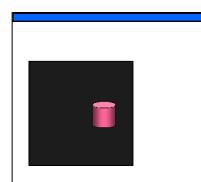
projection pipeline,



Projektovane normirane koordinate



Koordinate prozora

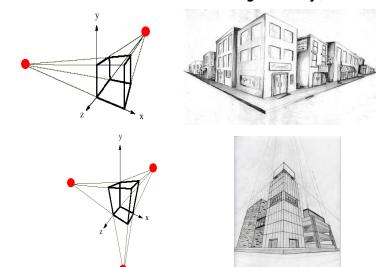
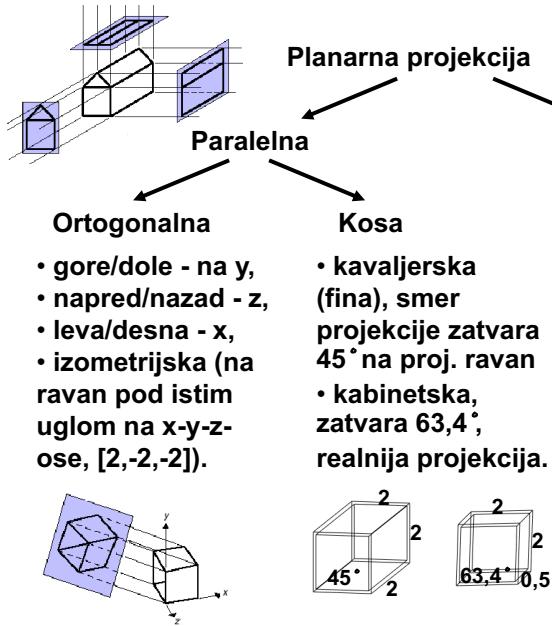


KLASE PROJEKCIJA

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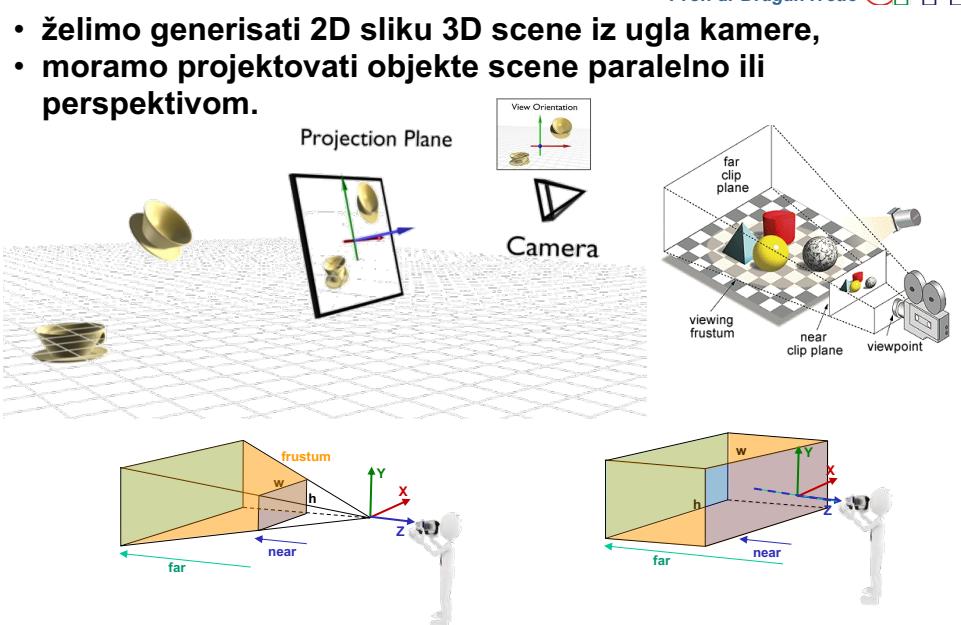


PROJEKCIJA POGLEDA

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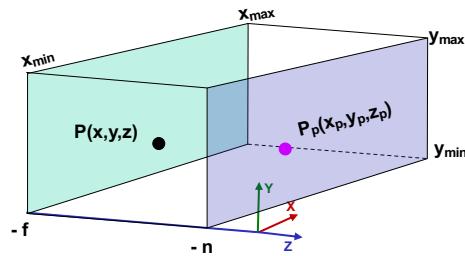
ORTOGONALNA PROJEKCIJA

na projekcionu ravan

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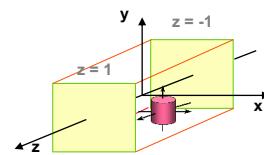


- bilo koju tačku $P(x,y,z)$ projektovati na front (-n),
- odrediti koordinate P_p
 x_p, y_p, z_p

$$\begin{bmatrix} x_p \\ y_p \\ z_p \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & d \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

- uvedemo projekcionu ravan d: 0 .. -f,

- Kako na kraju svesti kuboid na normiranu kocku? Normirane koordinate



ORTOGONALNA PROJEKCIJA

na normiranu kocku ...

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- OpenGL,

$$[x_p, y_p, z_p, 1]^T = M_{OrthoNorm} [x, y, z, 1]^T$$

$$M_{OrthoNorm} = \begin{bmatrix} \frac{2}{x_{\max} - x_{\min}} & 0 & 0 & 0 \\ 0 & \frac{2}{y_{\max} - y_{\min}} & 0 & 0 \\ 0 & 0 & -\frac{2}{f-n} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 1 & 0 & 0 & -\frac{(x_{\max} + x_{\min})}{2} \\ 0 & 1 & 0 & -\frac{(y_{\max} + y_{\min})}{2} \\ 0 & 0 & 1 & \frac{(f+n)}{2} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$M_{OrthoNorm} = \begin{bmatrix} \frac{2}{x_{\max} - x_{\min}} & 0 & 0 & -\frac{(x_{\max} + x_{\min})}{(x_{\max} - x_{\min})} \\ 0 & \frac{2}{y_{\max} - y_{\min}} & 0 & -\frac{(y_{\max} + y_{\min})}{(y_{\max} - y_{\min})} \\ 0 & 0 & -\frac{2}{f-n} & -\frac{(f+n)}{(f-n)} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

ORTOGONALNA PROJEKCIJA

na normiranu kocku ...

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- DirectX (LH sistem, max 1,1,1 i min -1,-1, 0)

$$M_{OrthoNorm} = \begin{bmatrix} \frac{2}{x_{\max} - x_{\min}} & 0 & 0 & 0 \\ 0 & \frac{2}{y_{\max} - y_{\min}} & 0 & 0 \\ 0 & 0 & \frac{1}{f-n} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 1 & 0 & 0 & -(x_{\max} + x_{\min})/2 \\ 0 & 1 & 0 & -(y_{\max} + y_{\min})/2 \\ 0 & 0 & 1 & -n \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$M_{OrthoNorm} = \begin{bmatrix} \frac{2}{x_{\max} - x_{\min}} & 0 & 0 & -\frac{(x_{\max} + x_{\min})}{(x_{\max} - x_{\min})} \\ 0 & \frac{2}{y_{\max} - y_{\min}} & 0 & -\frac{(y_{\max} + y_{\min})}{(y_{\max} - y_{\min})} \\ 0 & 0 & \frac{1}{f-n} & -\frac{n}{(f-n)} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

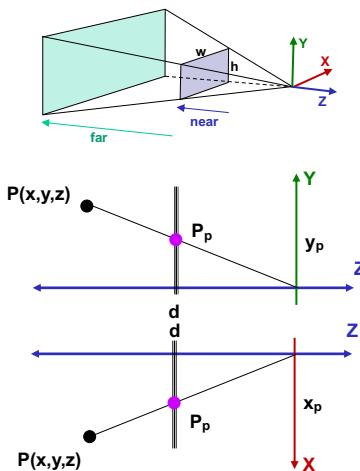
PROJEKCIJA U PERSPEKTIVI

na projekcionu ravan d

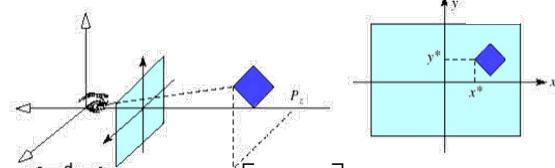
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$$\begin{aligned} x_p &= ? \\ y_p &= ? \end{aligned}$$



$$\begin{bmatrix} x_P \\ y_P \\ z_P \\ 1 \end{bmatrix} = \begin{bmatrix} -d \frac{x}{z} \\ -d \frac{y}{z} \\ -d \\ 1 \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ -\frac{z}{d} \end{bmatrix}$$

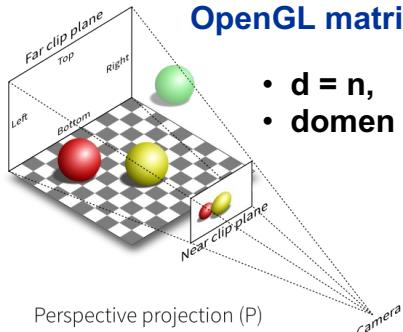
$$M_{Persp} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -\frac{1}{d} & 0 \end{bmatrix}$$

PROJEKCIJA U PERSPEKTIVI

OpenGL matrica projekcije ...

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- $d = n$,
- domen x_p vrednosti $l \leq x_p \leq r$

$$0 \leq x_p - l \leq r - l$$

$$0 \leq \frac{x_p - l}{r - l} \leq 1 \xrightarrow{*2} 0 \leq 2 \frac{x_p - l}{r - l} \leq 2$$

$$\xrightarrow{-1} -1 \leq 2 \frac{x_p - l}{r - l} - 1 \leq 1 \longrightarrow -1 \leq \frac{2x_p - 2l - r + l}{r - l} \leq 1$$

$$\longrightarrow -1 \leq \frac{2x_p}{r - l} - \frac{r + l}{r - l} \leq 1 \xrightarrow{x_p = \frac{n}{-z}} -1 \leq \frac{2nx}{-z(r - l)} - \frac{r + l}{r - l} \leq 1$$

$$\bullet \text{ domen } y_p \text{ vrednosti } b \leq y_p \leq t \longrightarrow -1 \leq \frac{2ny}{-z(t - b)} - \frac{t + b}{t - b} \leq 1$$

PROJEKCIJA U PERSPEKTIVI ... OpenGL matrica projekcije ...

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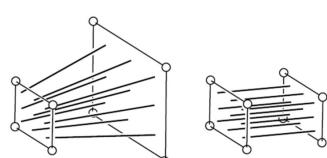
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$$\text{Kako domene } -1 \leq \frac{2nx}{-z(r - l)} - \frac{r + l}{r - l} \leq 1 \quad -1 \leq \frac{2ny}{-z(t - b)} - \frac{t + b}{t - b} \leq 1$$

ugraditi u matricu projekcije?

$$\begin{bmatrix} x_p \\ y_p \\ z_p \\ w \end{bmatrix} = \begin{bmatrix} \frac{2n}{r - l} & 0 & \frac{r + l}{r - l} & 0 \\ 0 & \frac{2n}{t - b} & \frac{t + b}{t - b} & 0 \\ 0 & 0 & A & B \\ 0 & 0 & -1 & 0 \end{bmatrix} * \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$



Kako ugraditi pseudo dubinu u matricu projekcije, z_p ?

$$z_p = \frac{A * z + B}{-z}$$

PROJEKCIJA U PERSPEKTIVI

... OpenGL matrica projekcije

- kako do a i b u pseudo_dubini?

- pseudo dubina = -1 ako je z = -n (near) $-1 = \frac{A*(-n) + B}{n}$

- pseudo dubina = 1 ako je z = -f (far) $1 = \frac{A*(-f) + B}{f}$

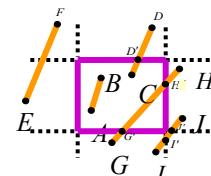
$$A = \frac{-(f+n)}{f-n}$$

$$B = \frac{-2fn}{f-n}$$

$$\begin{bmatrix} x_p \\ y_p \\ z_p \\ w \end{bmatrix} = \begin{bmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & -\frac{f+n}{f-n} & -\frac{2fn}{f-n} \\ 0 & 0 & -1 & 0 \end{bmatrix} * \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

CLIPPING

- razlika u veličini generativne grafike i rezolucije prikaznog uređaja,
- clipping linije, poligona, kruga, teksta u 2D,
- slično u 3D samo je reč o clipping kocki,



Mogući pristupi:

1. analitički - previše uzaludnog rada za mali (veliki) clipping prozor,

2. algoritamski - logičko usecanje prema graničnim pravama i/ili ravnima, radimo prvo 2D pa onda 3D:

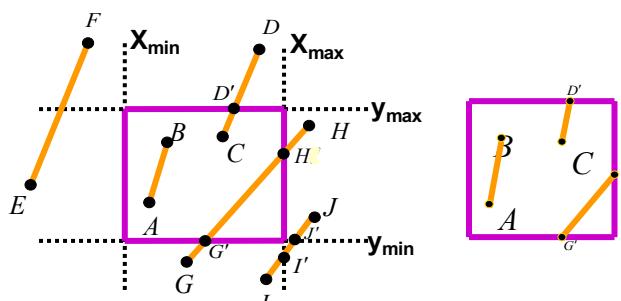
Cohen-Sutherland-ov algoritam, linija,
Sutherland-Hodgman-ov algoritam, poligon.

Opšta ideja algoritma:

1. prihvati **trivijalno unutr.** i odbaci **trivijalno spoljašnje linije,**

$X_{\text{maxLinija}} < X_{\text{max}}, X_{\text{minLinija}} > X_{\text{min}}, Y_{\text{maxLinija}} < Y_{\text{max}}, Y_{\text{minLinija}} > Y_{\text{min}}$
kako?

2. prihvati **delove ostalih linija** koje se nalaze unutar prozora,
podela na (pri) horizontalnim (vertikalnim) linijama,

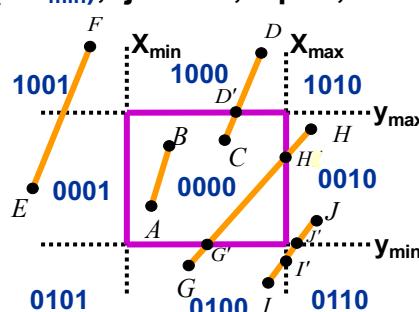


Implementacija?

Koliko selekcija?

Vreme izvršavanja?

- pametna podela ravni i njihovo kodiranje tetrada,
- do tetrade **šiftovanjem uлево predznaka ($y_{\text{max}}-y$) pa ($y-y_{\text{min}}$)**
pa ($x_{\text{max}}-x$) i ($x-x_{\text{min}}$), tj. iznad, ispod, udesno i uлево,



- linija EF ima tetrade (0001, 1001),
- kako jednostavno detektovati trivijalno prihvatljive,
odnosno neprihvatljive linije?

CLIPPING

... Cohen-Sutherland

- trivialno neprihvativ je ($tetrađa_A$ and $tetrađa_B \neq 0$), a trivialno prihvativ?
- kako preostale linije?

npr. GH → 0100 and 0010 = 0000, pa se deli na

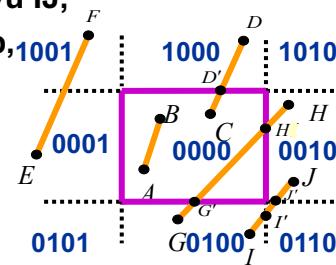
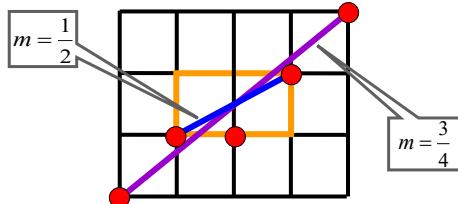
$GG' \rightarrow 0100$ and $0100 = 0100$, trivialno neprihvativ,

$G'H' \rightarrow 0000$ i 0000 , trivialno prihvativ pa u $G'H'$,

$H'H \rightarrow 0010$ and $0010 = 0010$, trivialno neprihvativ,

- nedostatak algoritma je račun za pravu IJ,

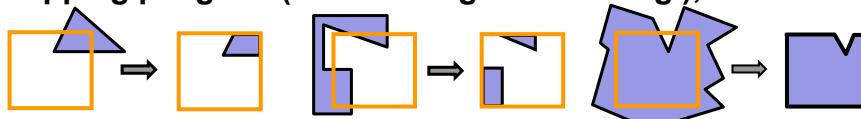
- ukrojena kriva može imati drugi nagib,



CLIPPING

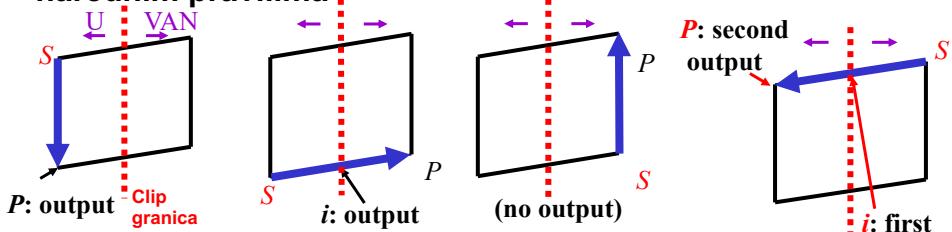
Sutherland-Hodgman ...

- clipping poligona (konveksnog i konkavnog),



Opšta ideja algoritma:

- Clip prema beskonačnim graničnim linijama prema narednim pravilima



- vektor tačaka poligona $t_1..t_N$ se menja svakim prolazom za svaku graničnu liniju (obično 4),

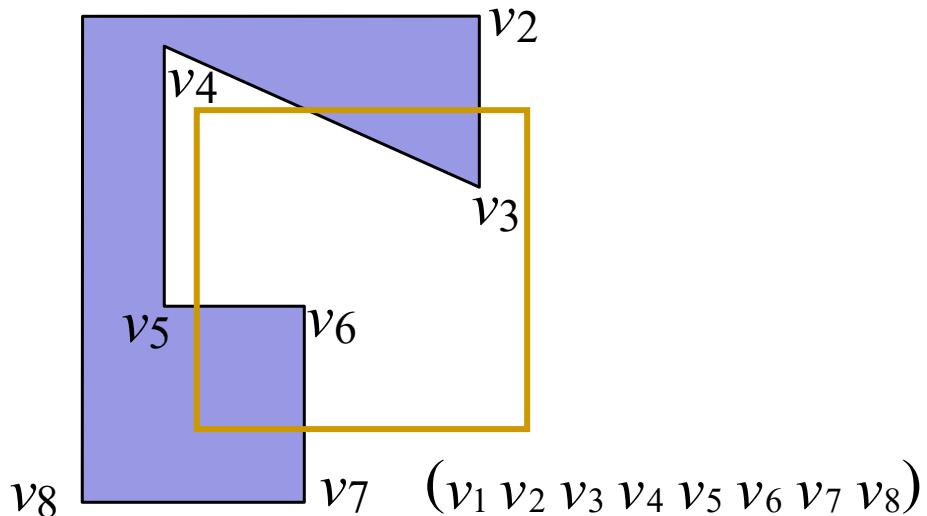
CLIPPING

... Sutherland-Hodgman ...

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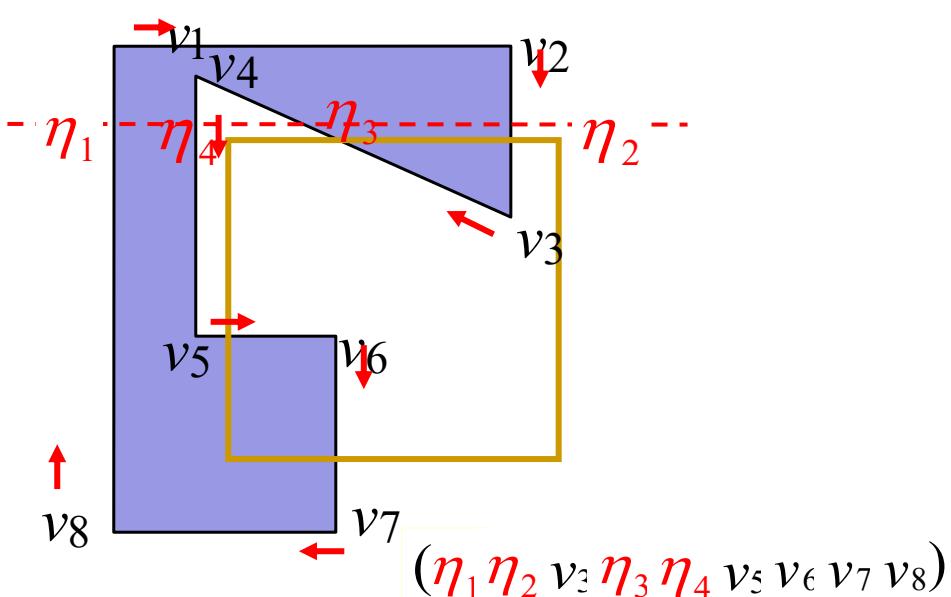
CLIPPING

... Sutherland-Hodgman ...

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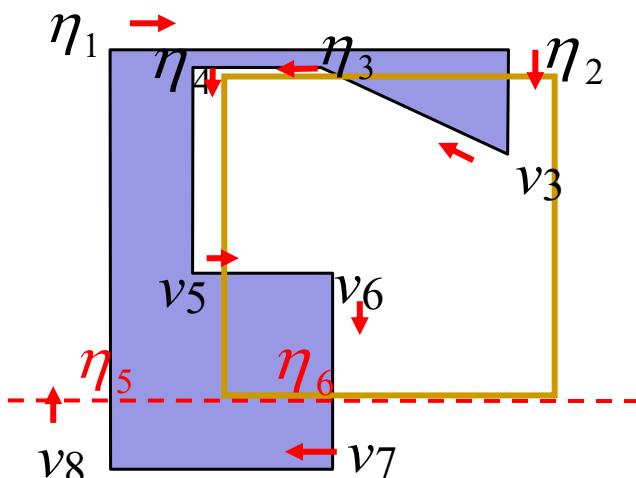
CLIPPING

... Sutherland-Hodgman ...

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$$(\eta_5 \eta_1 \eta_2 v_3 \eta_3 \eta_4 v_5 v_6 \eta_6)$$

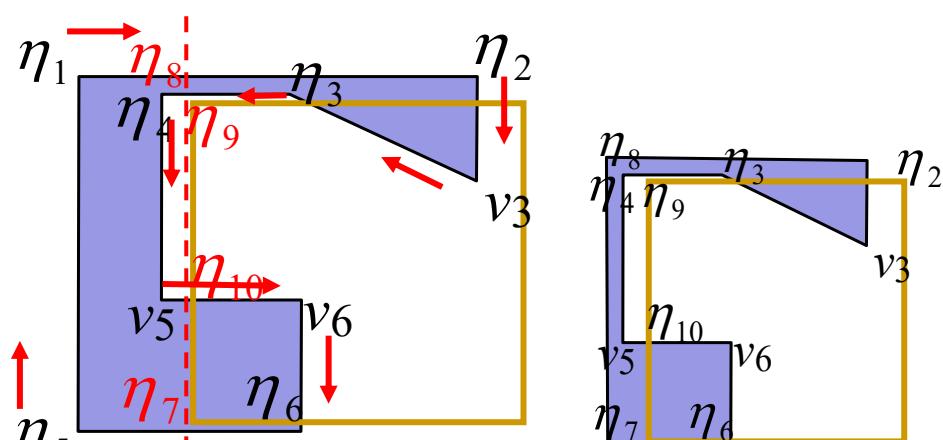
CLIPPING

... Sutherland-Hodgman

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$$(\eta_7 \eta_8 \eta_2 v_3 \eta_3 \eta_9 \eta_{10} v_6)$$

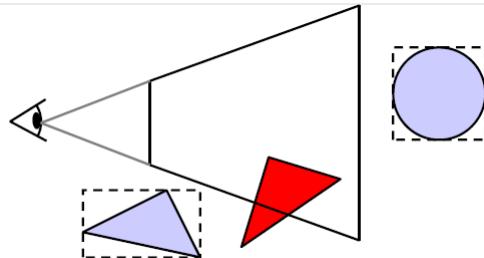
3D CLIPPING

v.s. culling

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Culling:

- odbacivanje prema graničnom volumenu,
- scena = hijerarhija graničnih volumena.

Clipping:

- parcijalno vidljivi objekti se moraju iskrojiti prema datom volumenu.

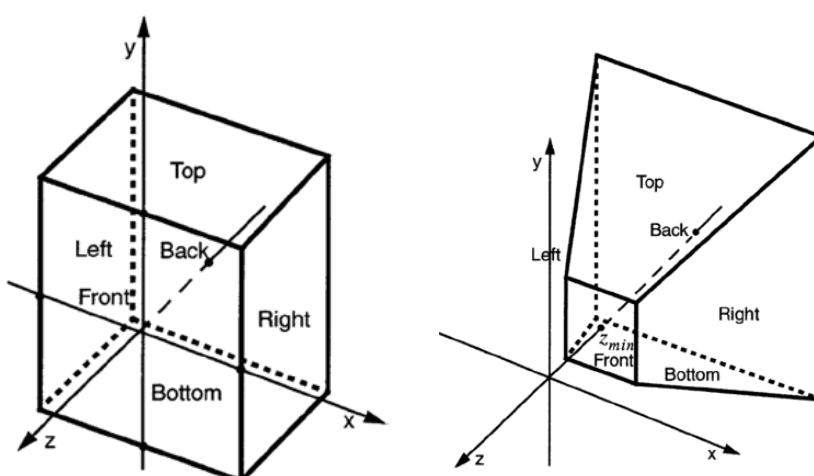
3D CLIPPING

i volumeni gledanja

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3D CLIPPING

Cohen-Sutherland

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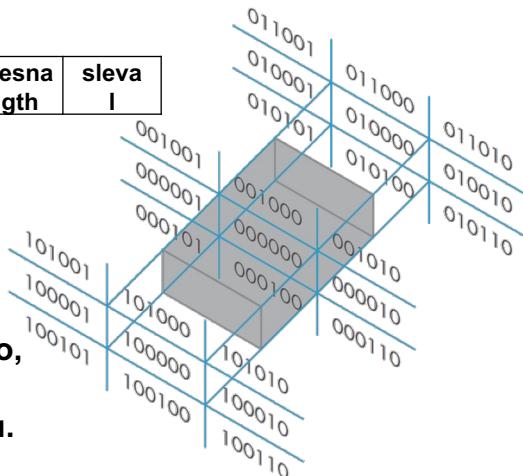
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**4-bitovski 2D algoritam (9 podravnji) proširen na
6-bitovski 3D algoritam (27 potprostora).**

ispred front	iza back	iznad top	ispod bottom	sdesna right	sleva left
-----------------	-------------	--------------	-----------------	-----------------	---------------

Nadalje kao u 2D:
a == b == 0 unutra trivijalno,
a & b == 0 moguće unutra,
a & b != 0 trivijalno napolju.



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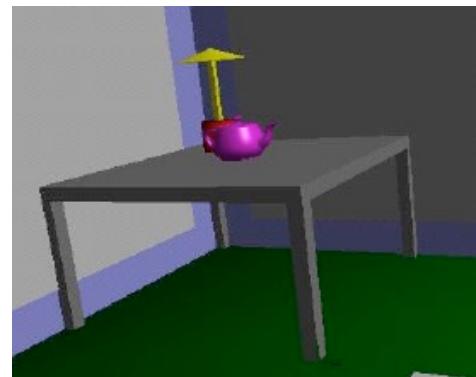
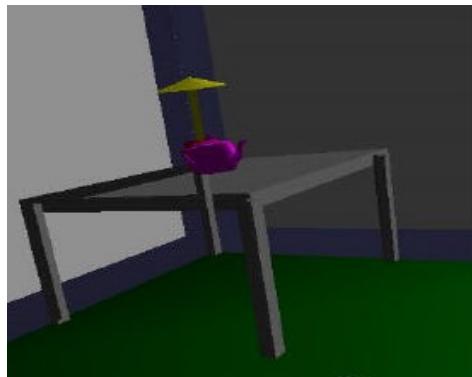
Zašto? ...

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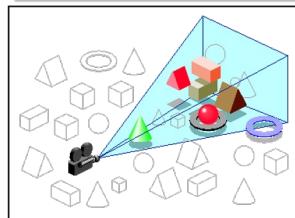
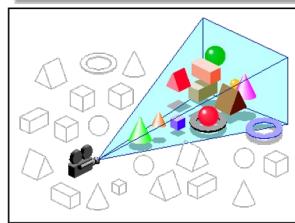
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- nisu vidljive baš sve površine na sceni,
- trošiti GPU na njih?
- realnost?



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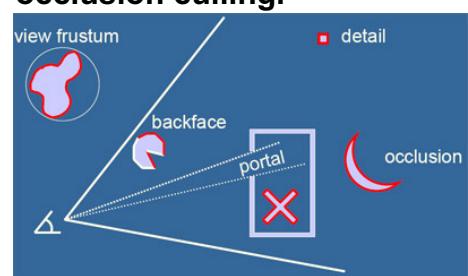
... Zašto?

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- površina postaje nevidljiva (hidden surface removal) jer je:
 - van vidnog polja viewing frustum culling,
 - pripada pozadini objekta back face culling,
 - je zaklanja jedan ili više objekata koji su bliži posmatraču occlusion culling.



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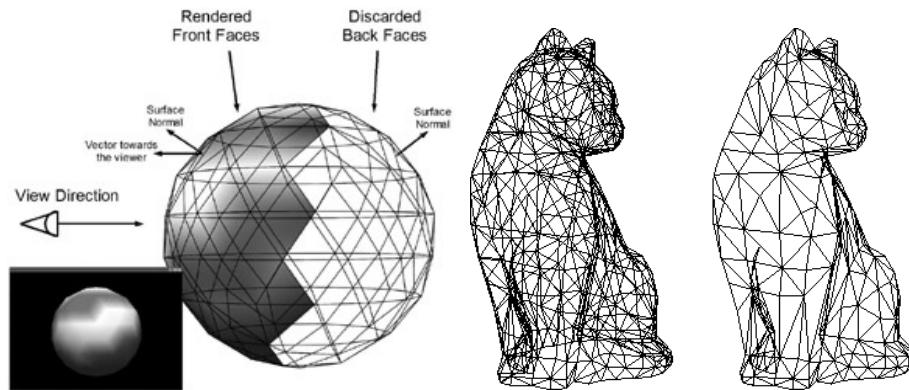
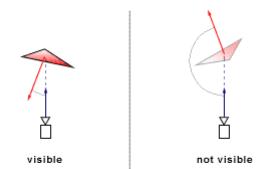
Back face culling

- ne prikazati površinu koja "gleda" u istom smeru kao i kamera,
- formalnije prikazati površinu akko
 $V_{\text{kamere}} \neq 0$? $N_{\text{površine}} \neq 0$.

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UKLONI SKRIVENO

Algoritmi za uklanjanje skrivenih površina

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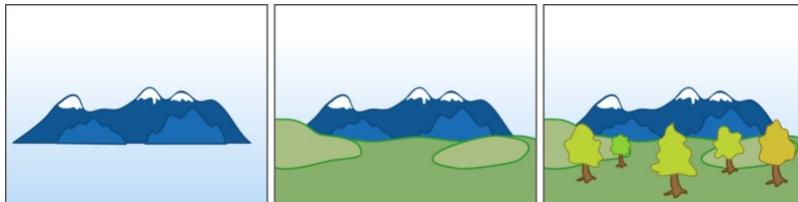
- da uklone (deo) površine koje su zaklonjene drugom/drugim površinama,
- pre rasterizacije temena - Object-space techniques
 - Painter's algorithm,
 - BSP trees,
 - portal culling,
- posle rasterizacije temena - Image-space techniques
 - Z – buffer,
 - α – buffer,
 - ray tracing.

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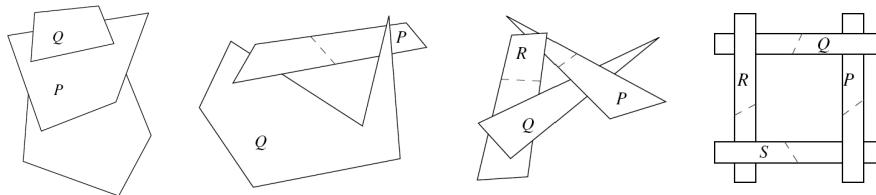
Painter's algorithm

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- prikazivanje površina od pozadinskih prema frontalnim,



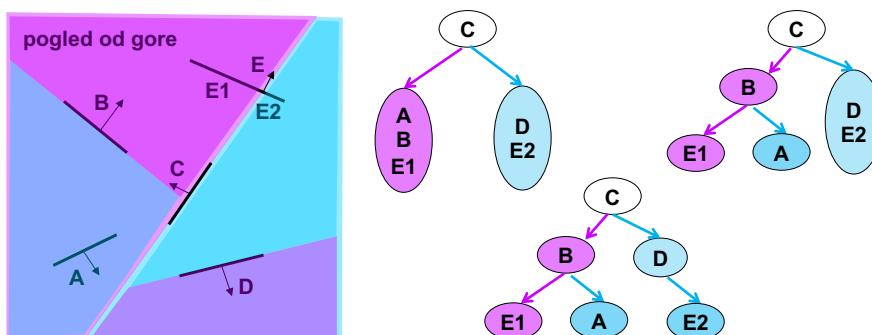
- podržava transparentnost,
- problemi sa sortiranjem površina (broj, pozicija kamere...).



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BSP stablo ...
Prof. dr Dragan Ivetić


- Binary Space Partitioning tree,
- prostor se deli na **ispred** / **iza** ravni koja sadrži poligon,
- ako ravan preseca neki drugi poligon, on se deli na dva potpoligona....,
- nastaviti dok svaki čvor stabla bude jedan poligon,
- takvo stablo će definisati redosled prikaza poligona,

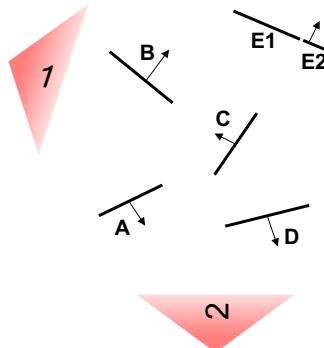
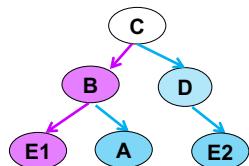


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... BSP stablo

- kako prolaziti kroz stablo do liste redosleda prikaza?
- gledalac ispred → potprostor desnog podstabla, koren, potprostor levog podstabla,
- gledalac iza → potprostor levog podstabla, koren, potprostor desnog podstabla,
- gledalac na granici → ?

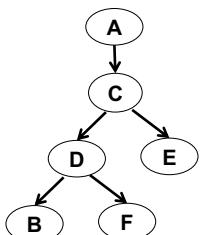
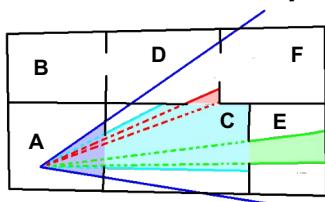
- gledalac 1 → D E2 C E1 B A,
- gledalac 2 → ?



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Portal culling

- zasnovan na grafu ćelija i portala (vrata),
- prvo se renderuje ćelija gde je posmatrač, pa onda onoliko koliko se vidi kroz portale...



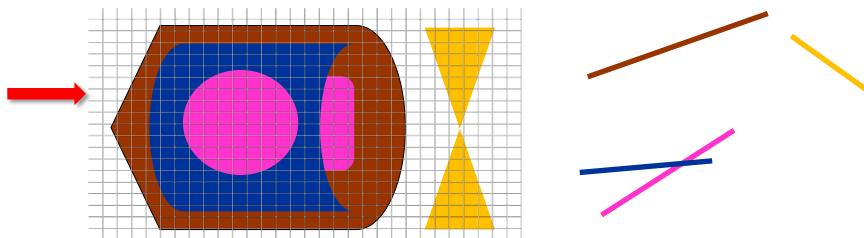
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Z-buffer ...

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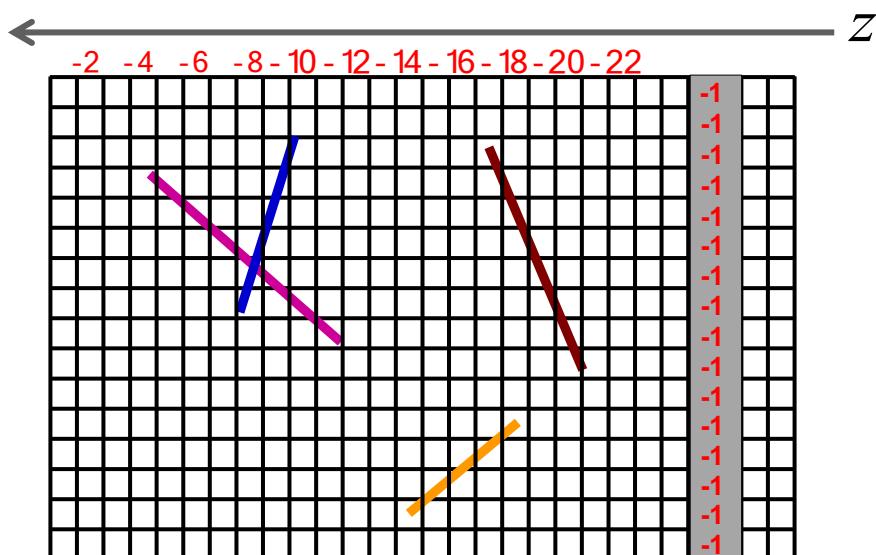
- image-space tehnika,
- osnovna ideja Z-buffer:
 - inicijalno Z-buffer elementi na -1,
 - rasterizuj svaki ulazni poligon,
 - za svaki piksel interijera, interpoliraj njegov Z,
 - upiši (Z vrednost i) boju u njegov deo bafera akko je Z veća od postojeće u baferu,
 - prikaži vrednosti boja iz bafera.



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... Z buffer ...

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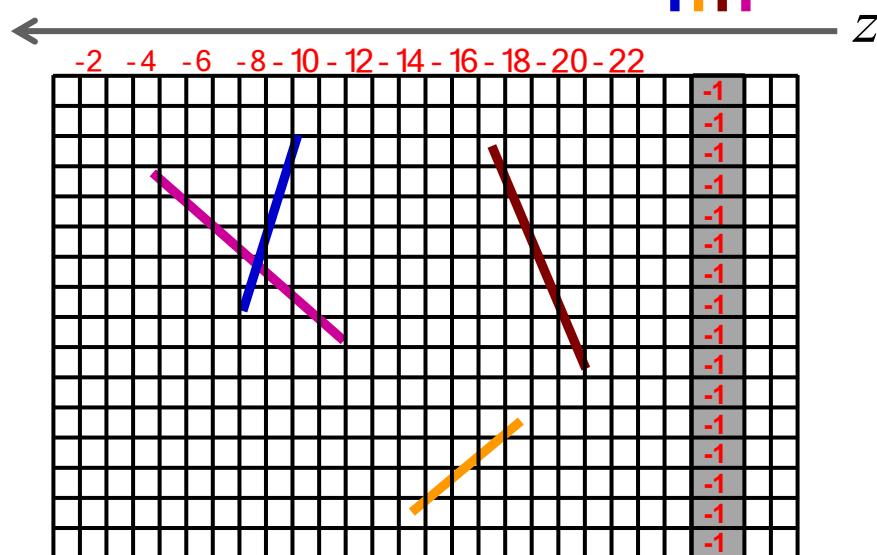


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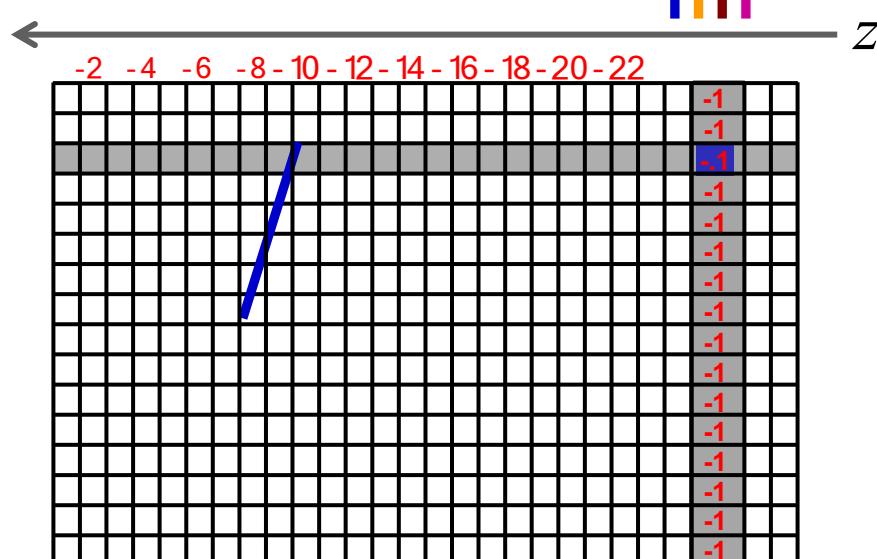


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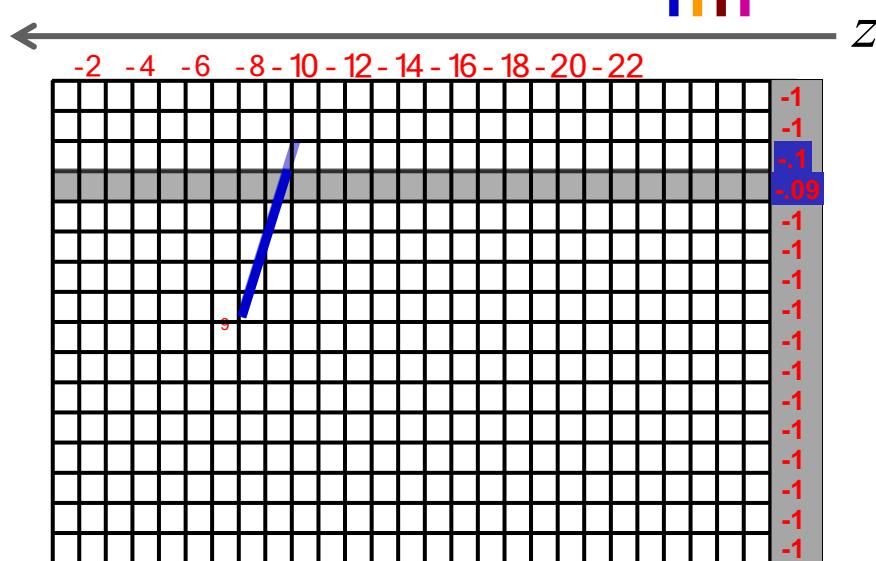
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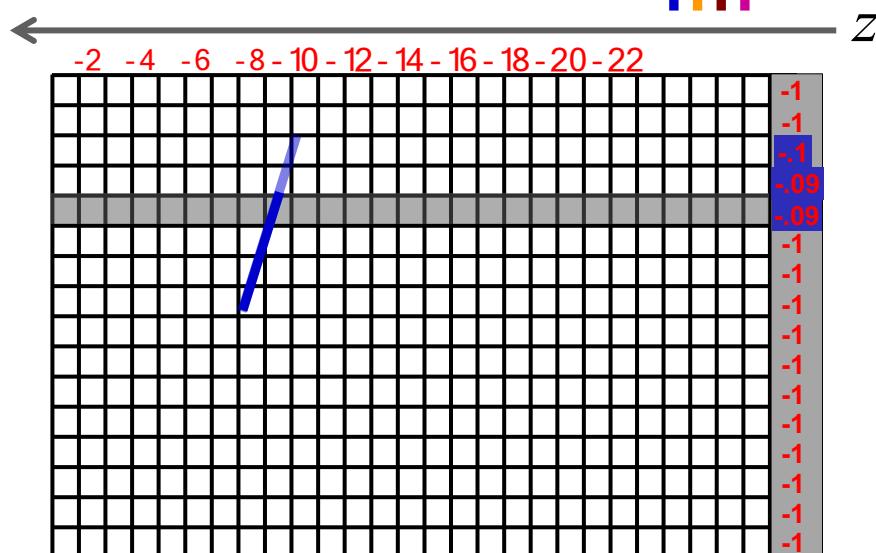
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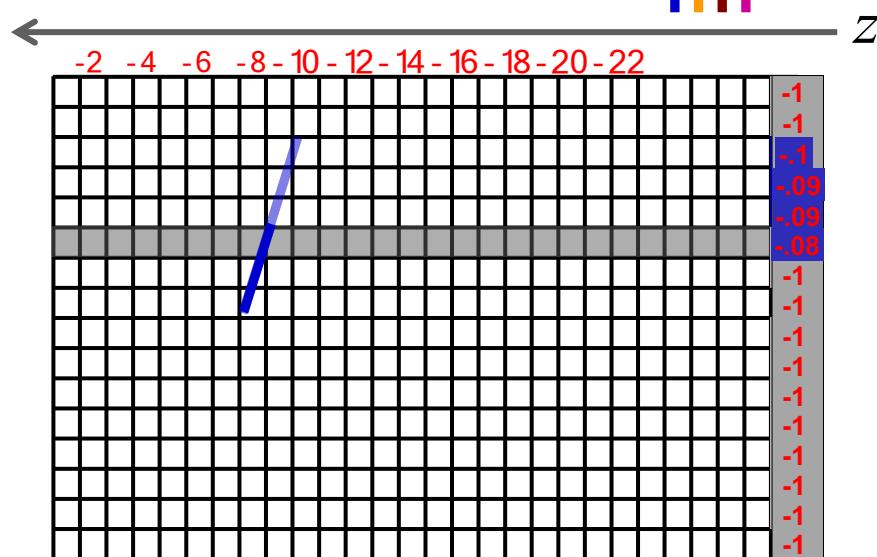
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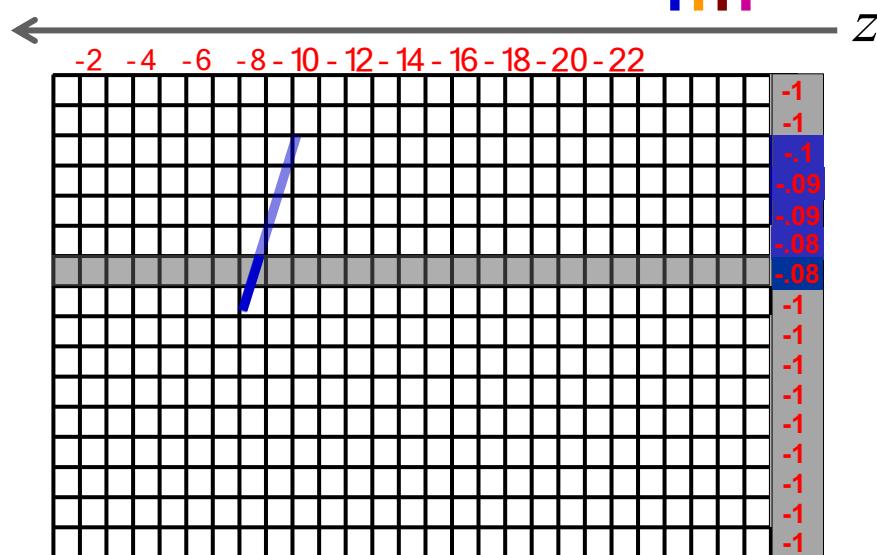
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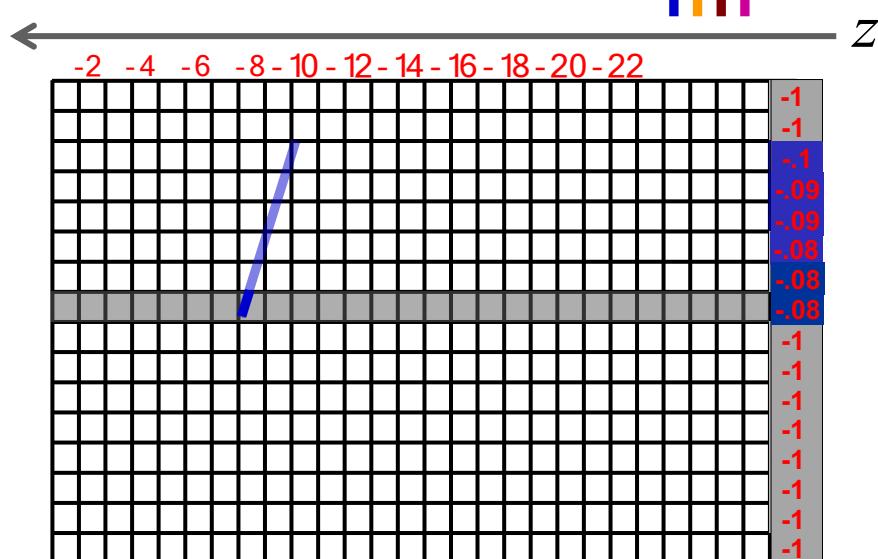
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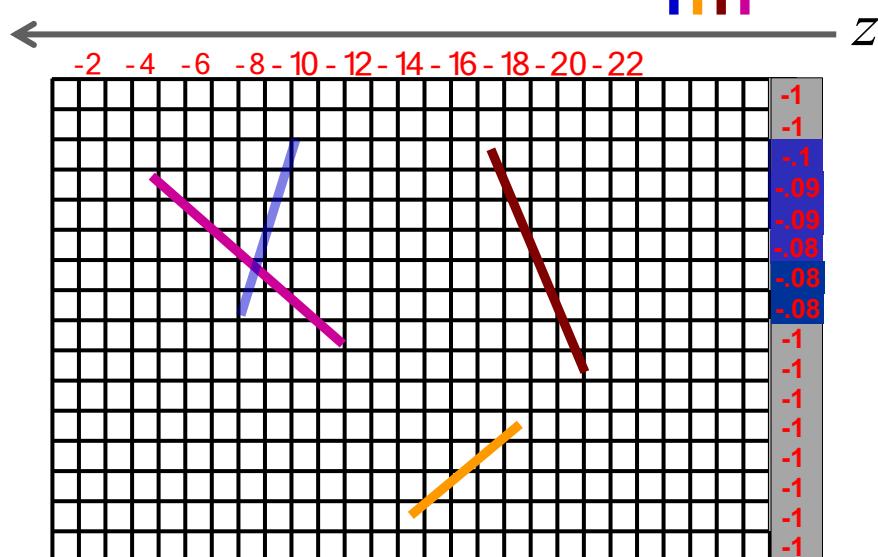
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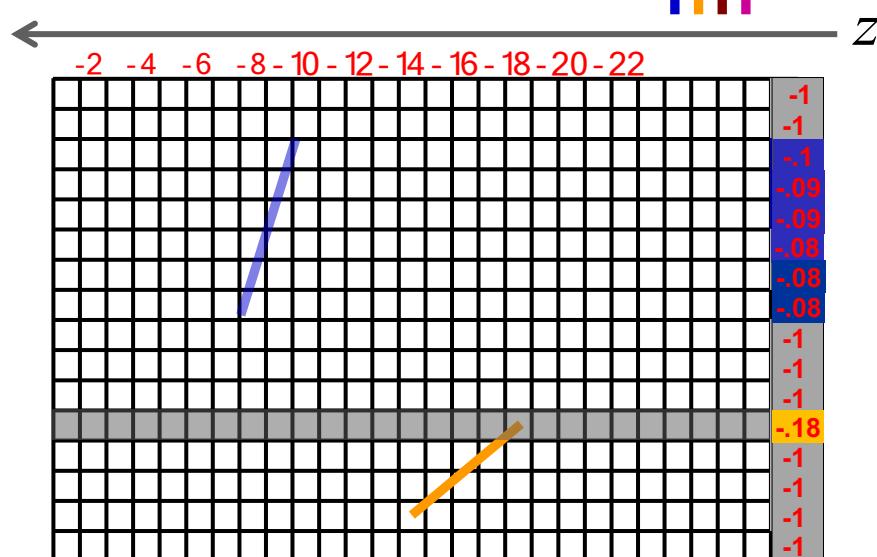
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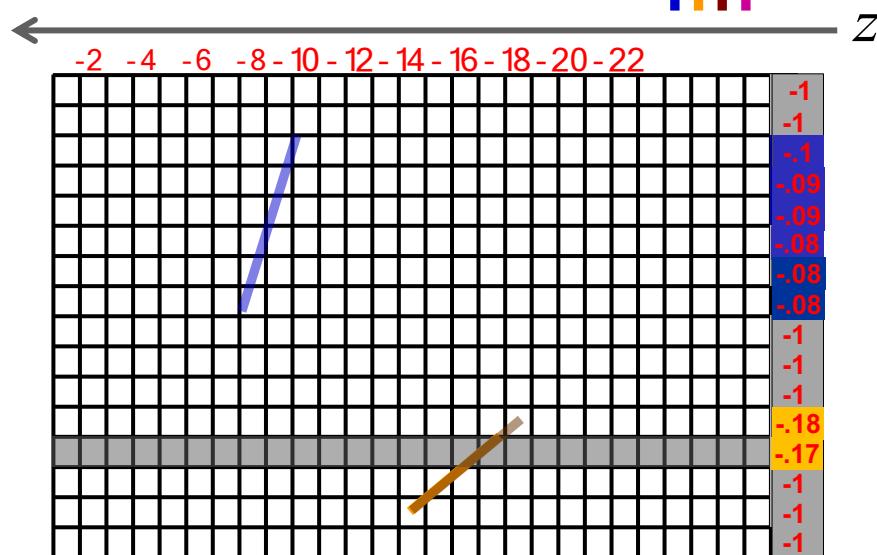


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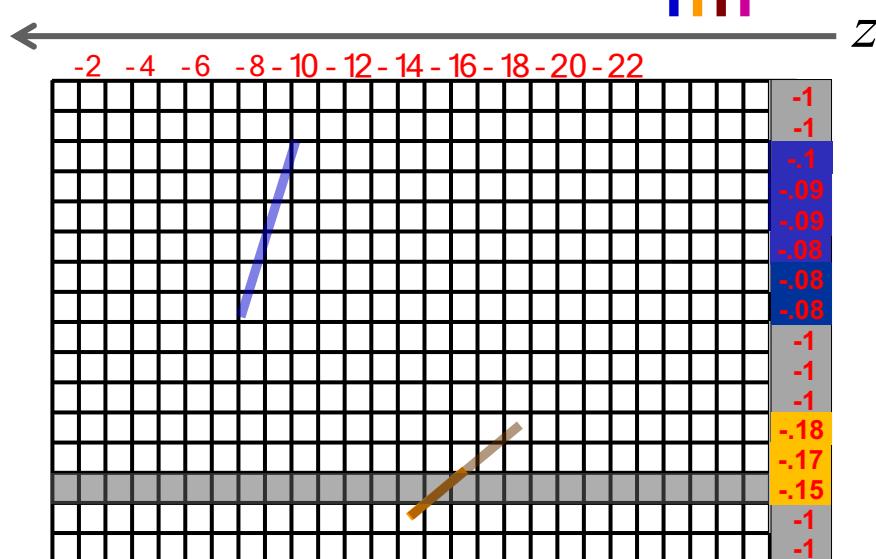


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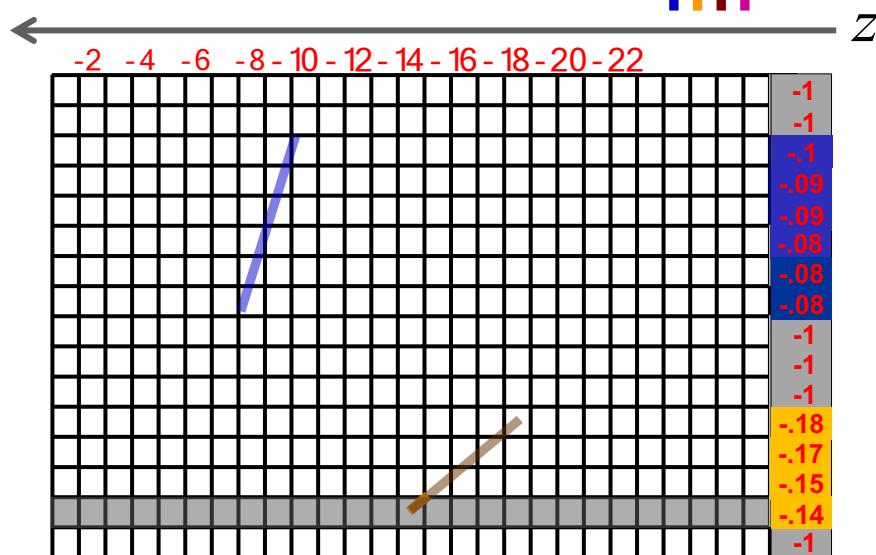


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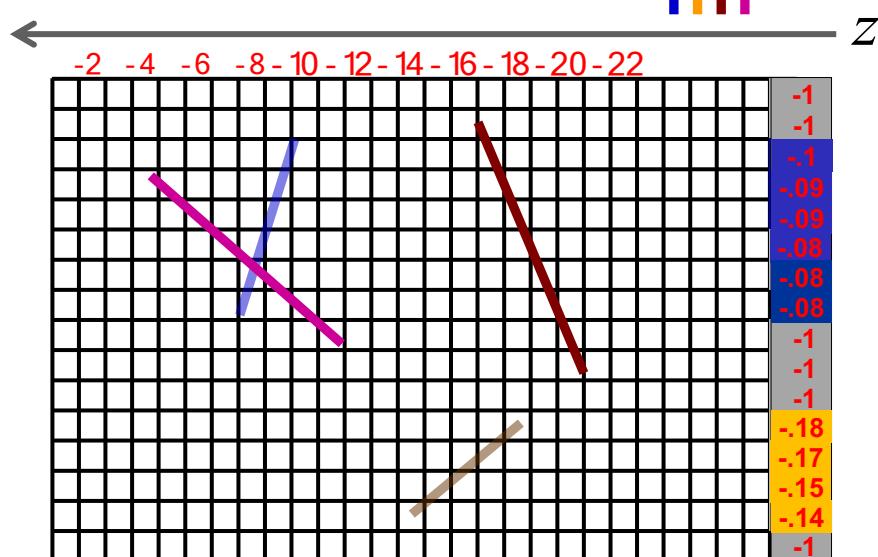


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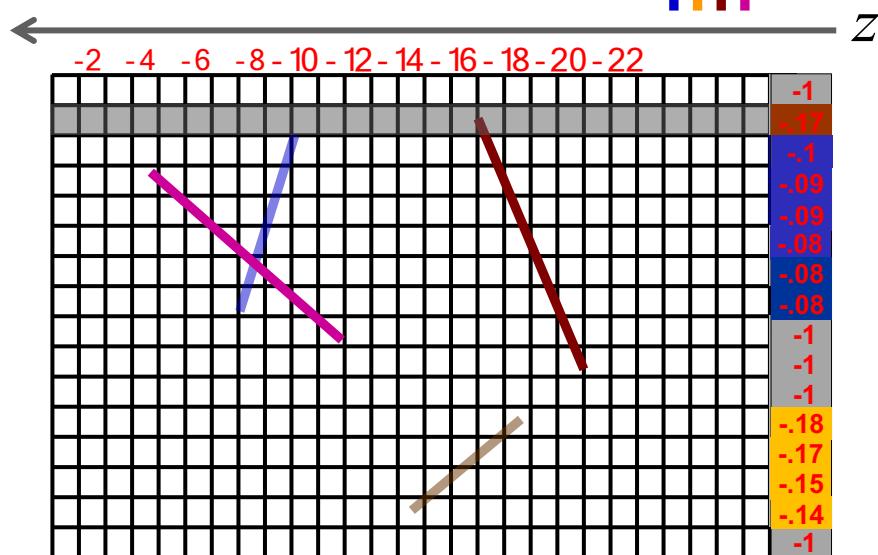


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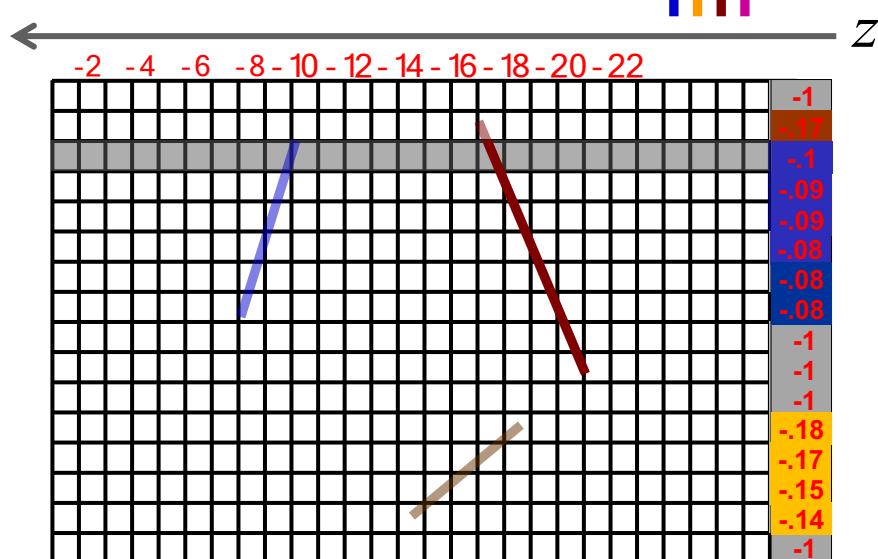


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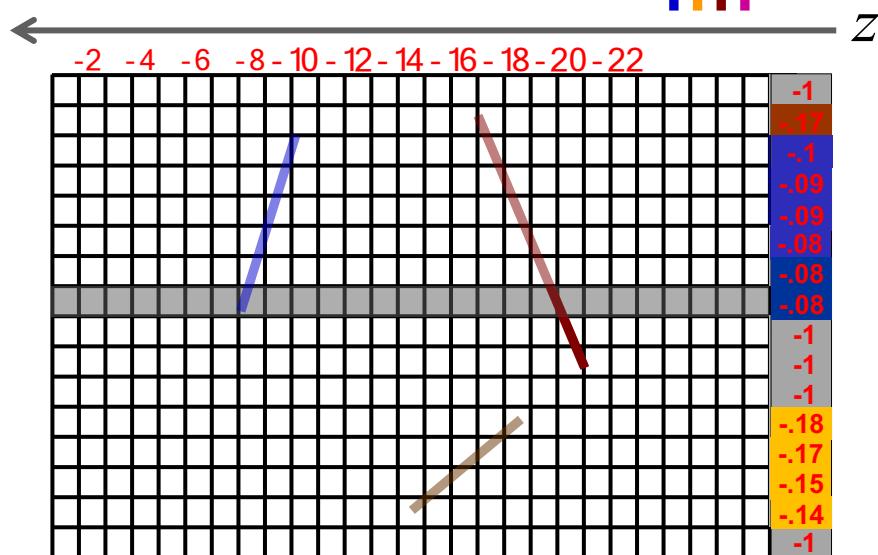


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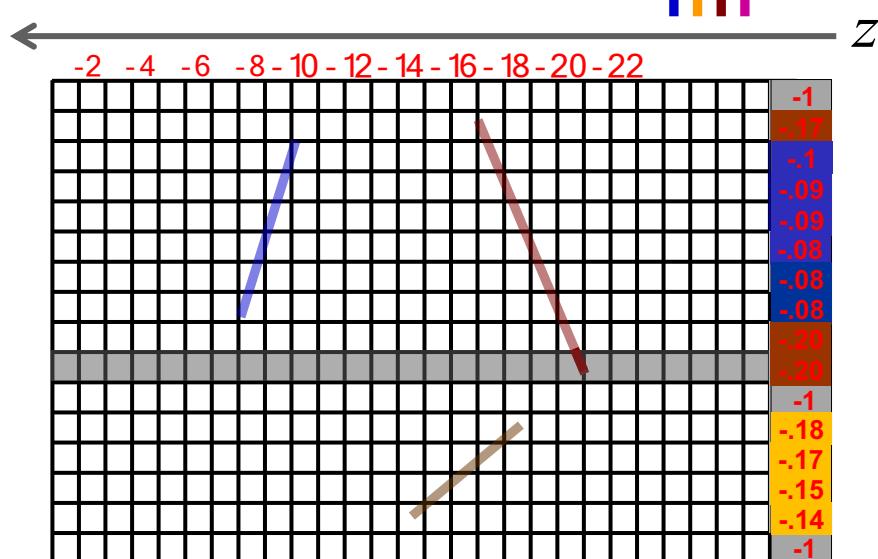


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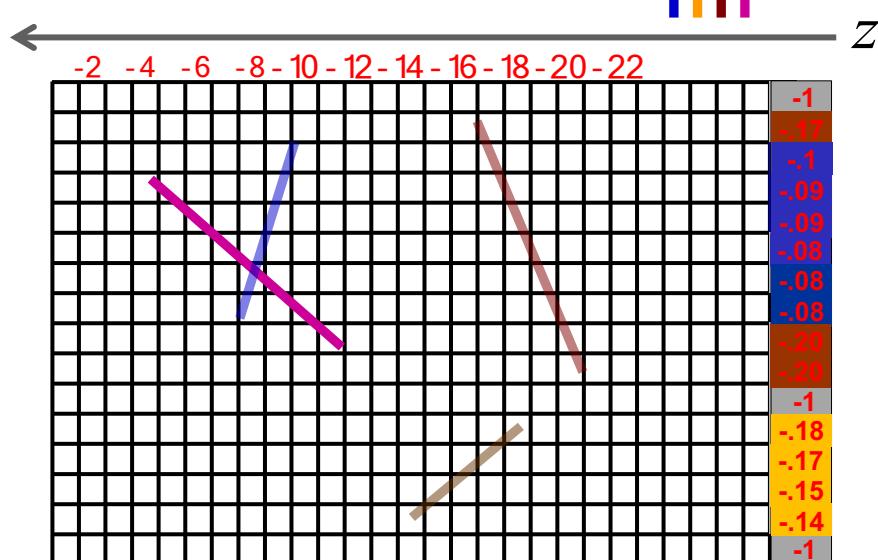


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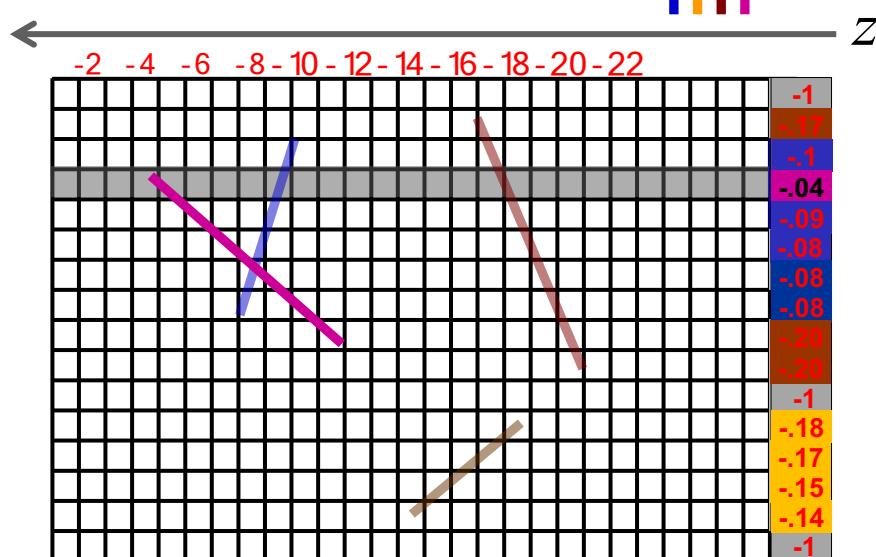
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UKLONI SKRIVENO

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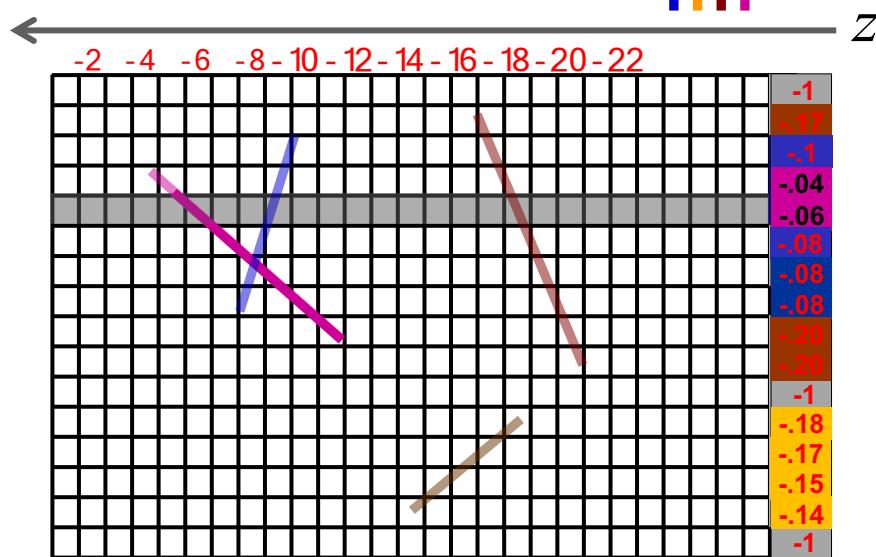
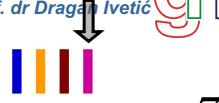
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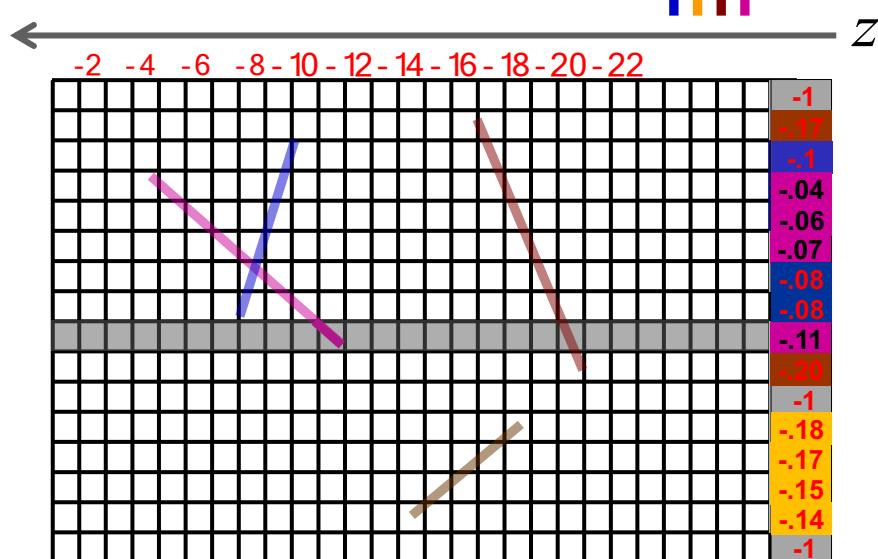
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UKLONI SKRIVENO

... Z buffer ...

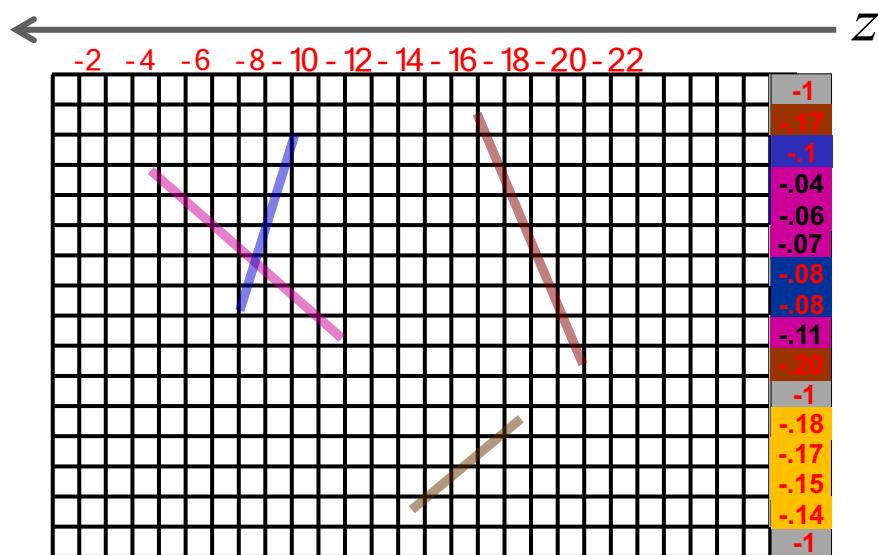
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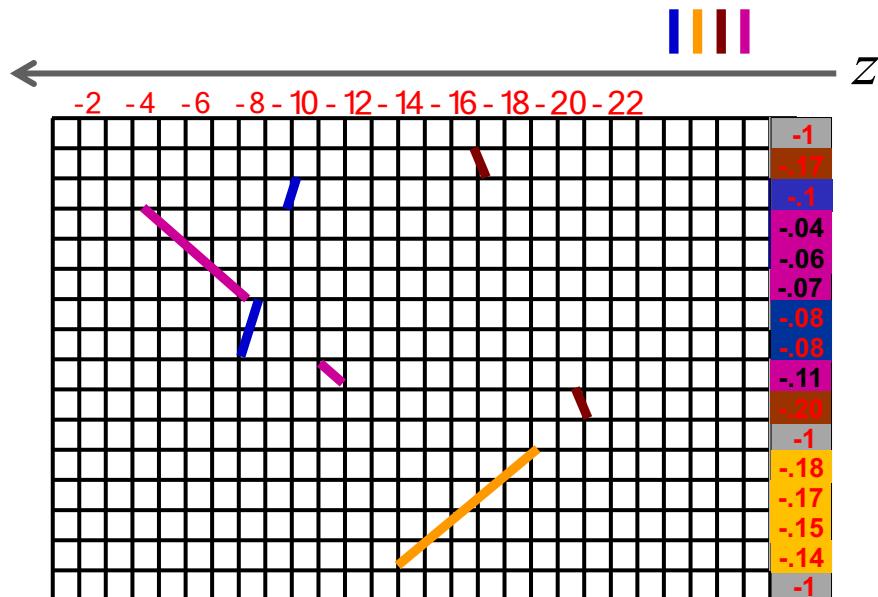


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... Z buffer ...

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**ZA**

- jednostavan algoritam, ide u HW,
- za svaku scenu, nema sortiranja,
- kompleksnost $O(N)$,
- nema zavisnosti od redosleda poligona,
- dušu dao za paralelnu obradu.

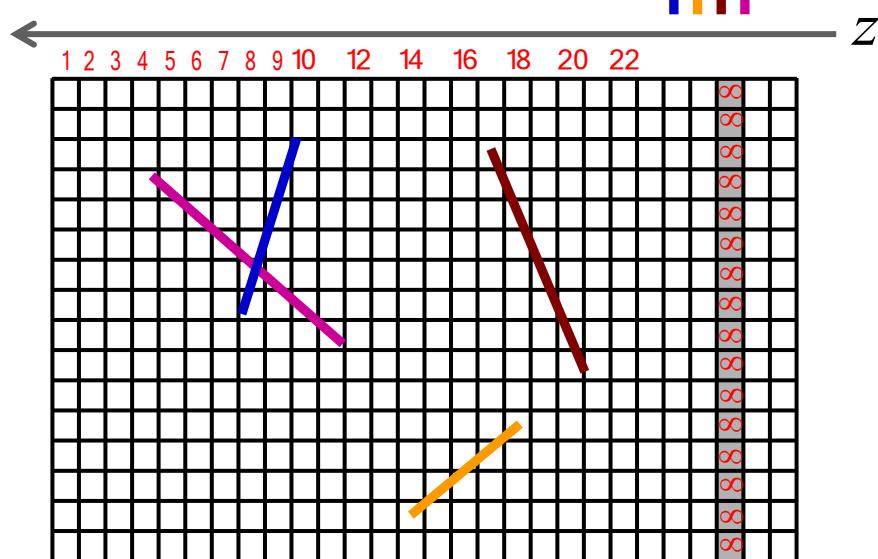
PROTIV

- zahtevan za memorijom,
- radi i sa očigledno skrivenim (BSP, portal culling),
- nezgodan za antialiasing, transparentnost, foreground/background, i sl.

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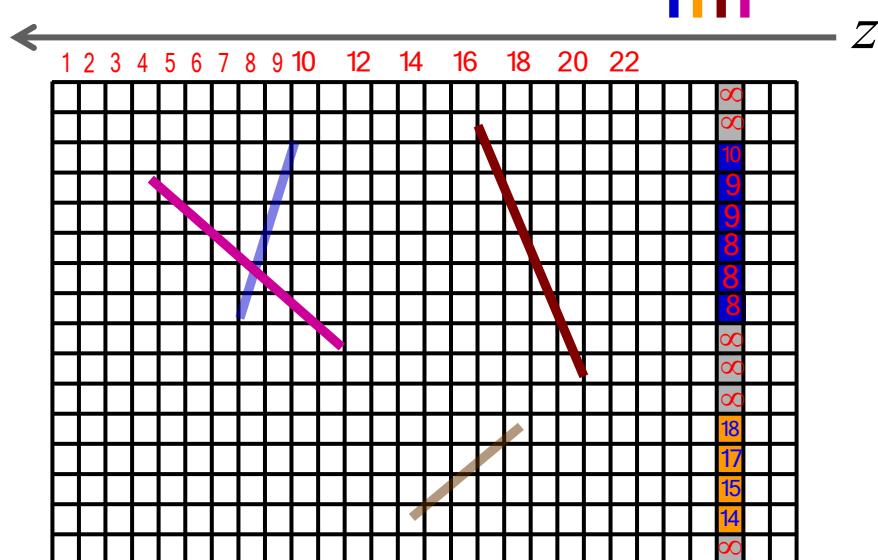
2012/2013



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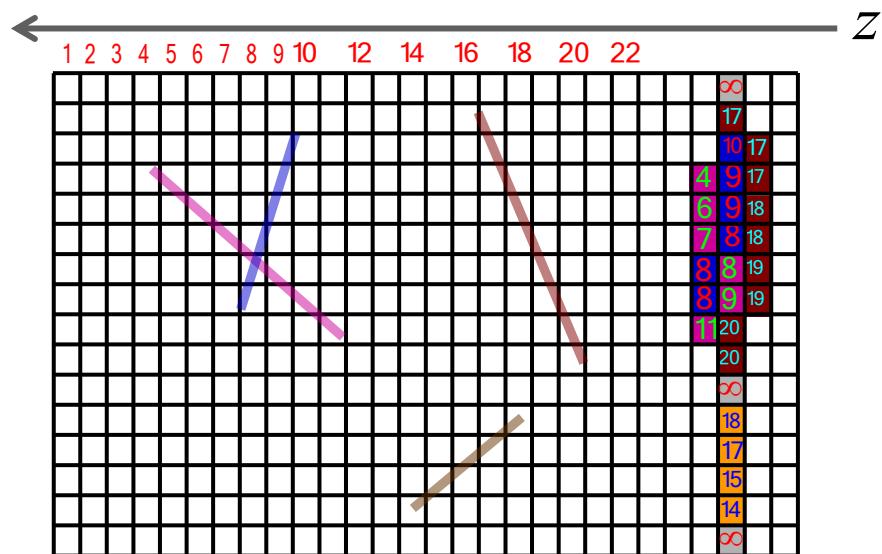
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