Prof. dr Dragan Ivetić

RAČUNARSKA GRAFIKA

skripta

SEDAMNAESTA GENERACIJA STUDENATA

Novi Sad, 2017. godine

Kome i kako?

RAČUNARSKA GRAFIKA 2016/2017
Prof. dr Dragan Ivetić

RAČUNARSKA GRAFIKA (RI4A), 3 + 2
(na FTN od 2001./2002. školske godine)

Dr Dragan Ivetić, redovni profesor

E2 Primenjene računarske nauke i informatika, 7. semestar
Animacija u inženjerstvu (ANI), 3. semestar

Nenad Milić, (E2, ANI)
Milan Adamović, (ANI, E2)

O nastavniku

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Prof. dr Dragan Ivetić

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.

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.

Jugodrvo 202, Bulevar Oslobođenja 133, Novi Sad
(021) xxx-xxxx, 485-2424 (AI xx/yyyy i ftn)
http://gim.ftn.uns.ac.rs ivetic@uns.ac.rs

Kako položiti predmet?

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1. **Predispitne obaveze, do 70 bodova:**

   vežbe (poznavanje OpenGL) – 50 bodova + deskriptor.

   teorija u praksi (pitanja na vežbama u 2 navrata) – 20 bodova,

   Potpis se dobija bez uslova.

2. **Završni ispit (moguće 3 isključive varijante)**
   1. **BEZ (vežbe>24, T. pitanja>14 i nikada GIM) – 55..70 (potpisana saglasnost u januaru, junu ili septembru)**
   3. **Usmeni 30 minuta (15.. 30), (vežbe>24), – 55 .. 100, termini na GIMu tokom JAN FEB MART APR MAJ, 2 puta maksimalno, u suprotnom sve ponovo**

Literatura

RAČUNARSKA GRAFIKA 2013/2014
Prof. dr Dragan Ivetić

1. SLAJDOVI SA PREDAVANJA SA VAŠIM BELEŠKAMA
2. Hughes, V. Dam, McGuire, Sklar, Foley, Feiner, & Akeley, COMPUTER GRAPHICS Principles and Practice, 2013.
3. Peter Shirley, Steve Marschner, with ..., FUNDAMENTALS OF COMPUTER GRAPHICS, 3rd Ed, 2009.
4. Akenine-Möller T., Heines E. and Hoffman N, REAL-TIME RENDERING, 3rd Ed., 2008.
5. Rick Parent, COMPUTER ANIMATION: ALGORITHS AND TECHNIQUES, Morgan Kaufmann, 2002.
6. Shreiner, Sellers, Kessenich, Licea-Kane, OpenGL 4.3 Programming Guide, 8th ed, 2013.

Oblasti računarske grafike

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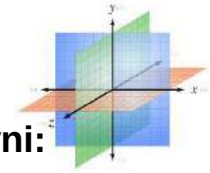
su:

- **Generativna grafika**
  - konstrukcija objekata i generisanje slike,
  - transformacija objekata i slike,
  - identifikacija objekata i info. retrievel
- **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)

Osnovni pojmovi i procesi



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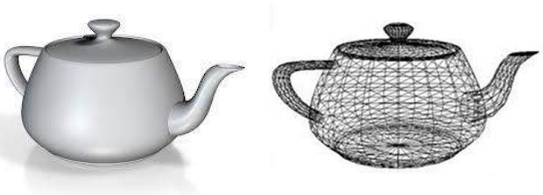
Samo 3D esencijalni i perceptivni:

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



Real-Time (interaktivna) grafika

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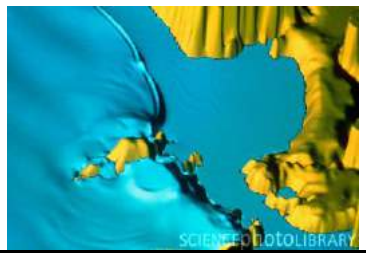
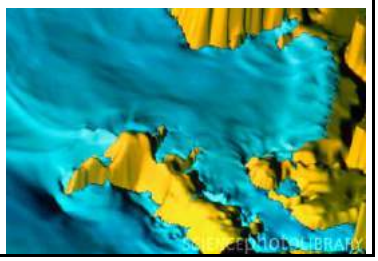
Simluacije





Real-Time (interaktivna) grafika

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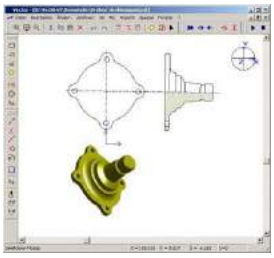
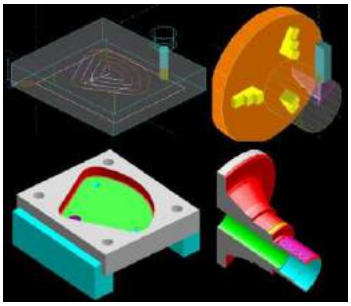
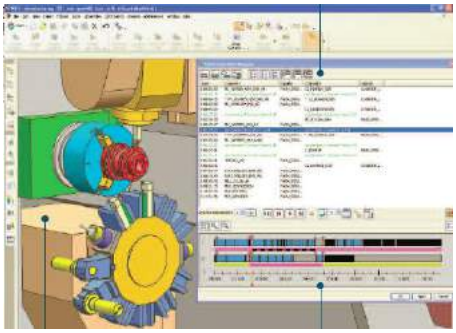
CAD, CAA i CAM

Real-Time (interakt

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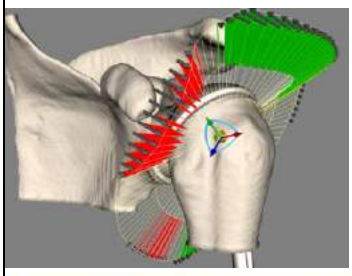
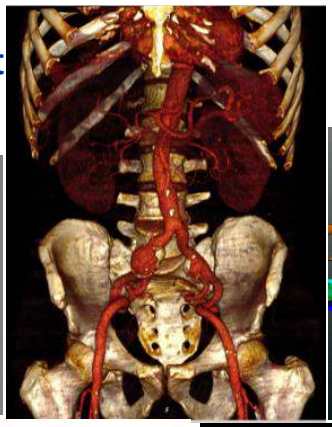
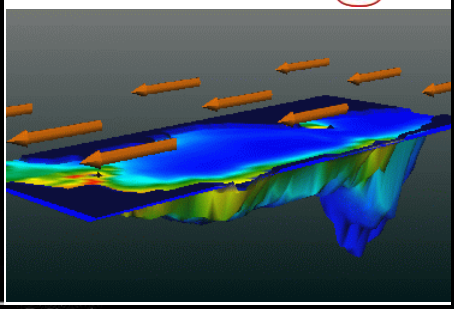
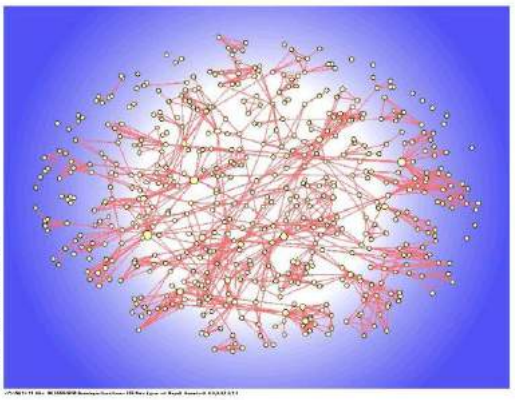
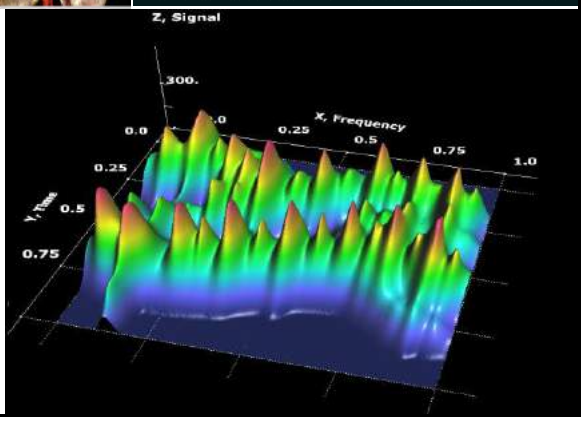
Vizuelizacija

Real-Time (interaktivna) grafika

Virtuelna/augmentovana stvarnost

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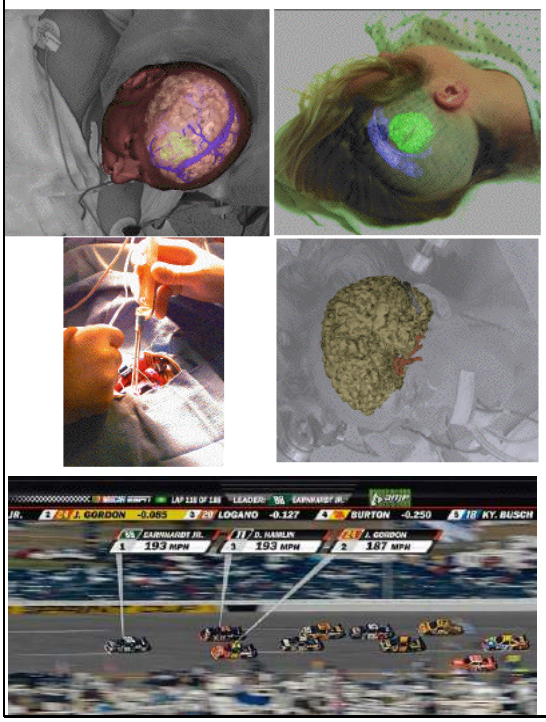

Real-Time (interaktivna) grafika

HCI i novi infromacioni prostori

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Real-Time (interaktivna) grafika

Računarske igre





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Non-Real-Time grafika

Film (umetnost)


Non-Real-Time grafika
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2013/2014
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Film
Shrek(01 04 07 10)
Up (2009)
Finding Nemo (2003)
IceAge (06 09 12)
Ratateuille (2007)
Monster Inc. (01 13)
Despicable Me (10 13)
Madagascar 05 08 12
Kung fu panda(08 11)
Brave (2012)
Adv. of Tintin (2011)


Non-Real-Time grafika
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Film

Non-Real-Time grafika

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Film

Non-Real-Time grafika

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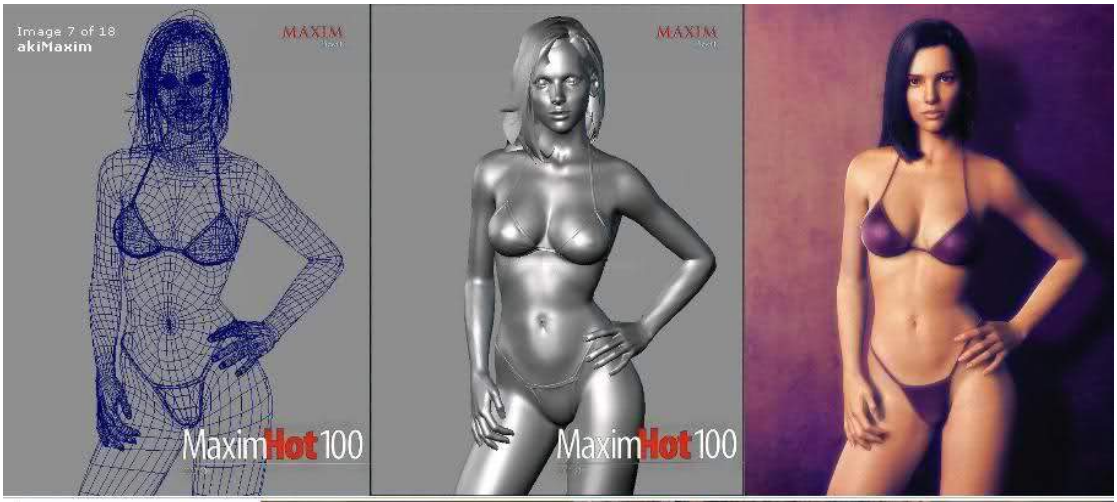
Film



Real-Time stiže non-Real-Time kvalitet?

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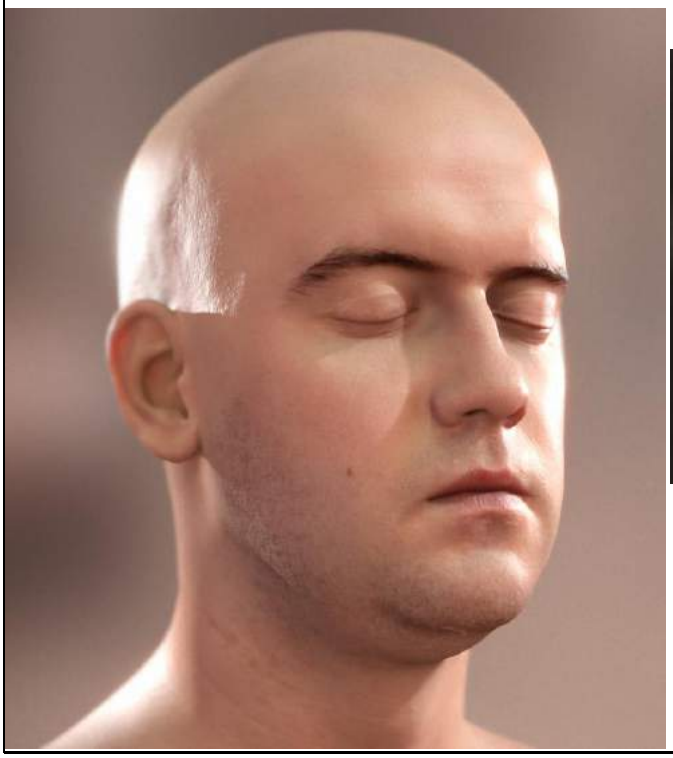

Real-Time Rendering of Realistic Human Skin with a Two-Gaussian HDR Bloom Filter

Softverski režimi grafičkog prikaza

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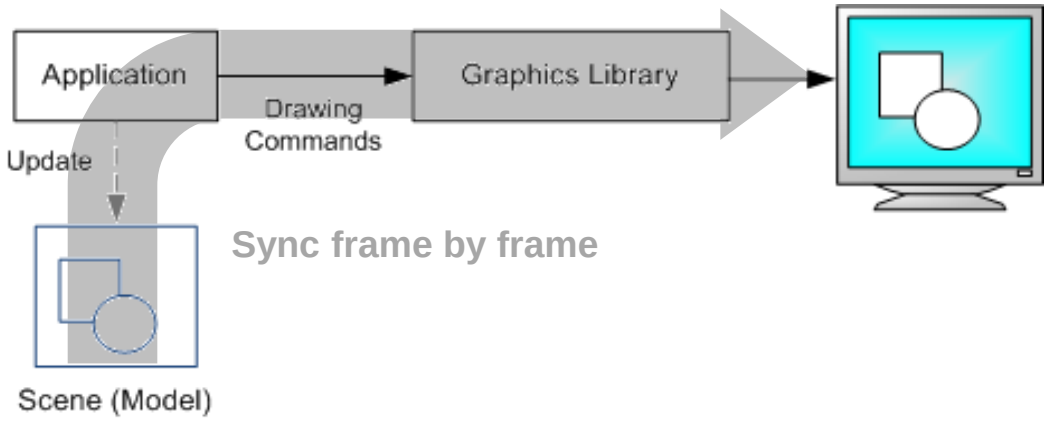
Immediate-mode (neposredni režim)

- **na najnižem nivou, proceduralno, direktno ka HW,**
- **OpenGL/DirectX biblioteke u osnovnoj upotrebi,**
- **progamski se kontroliše šta se upravo iscrtava.**



Softverski režimi grafičkog prikaza

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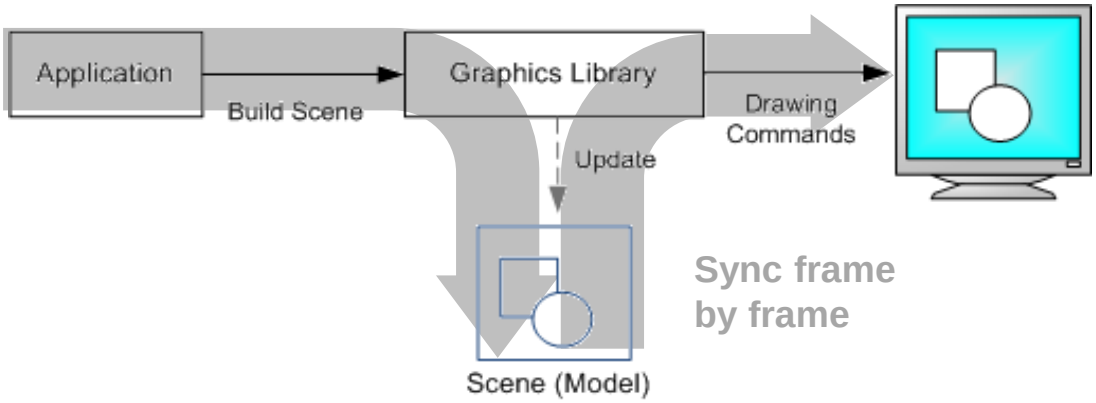
Retained-mode (posredni režim)
- **na višem nivou, deklarativno,**
- **OpenGL/WPF(DirectX) biblioteke,**
- **briga programera samo pri promeni scene.**



Ko je brži? Ko je manje komunikaciono zahtevan?

VEKTOR I/ILI TAČKA (raster) …

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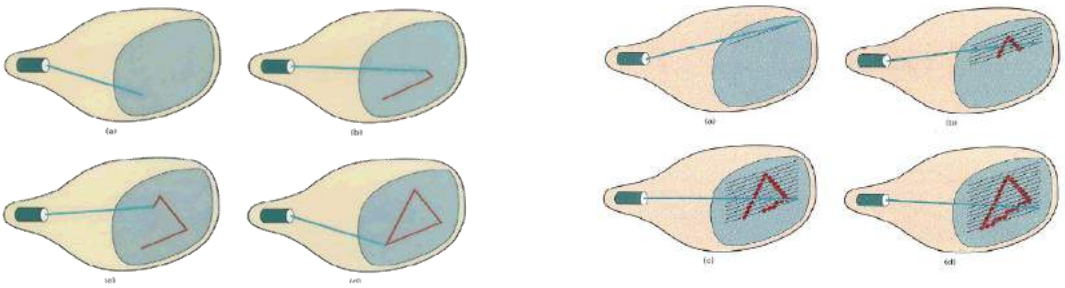

a može biti sprovedeno na nivou:

Softvera (logika) - i to na podnivou

instrukcije/komande, ili

podataka.

Hardvera (fizika).

... VEKTOR I/ILI TAČKA (raster) …

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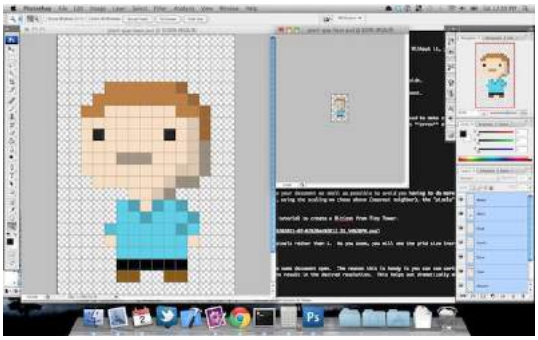
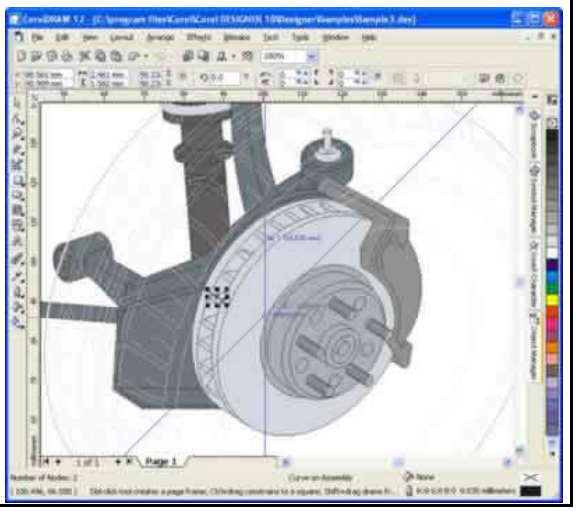
Instrukciono logički (SW) – da li korisnik formira grafički prikaz angažujući komande nad tačkom (PhotoShop) ili vektorom (CorelDraw).





… VEKTOR I/ILI TAČKA (raster) …

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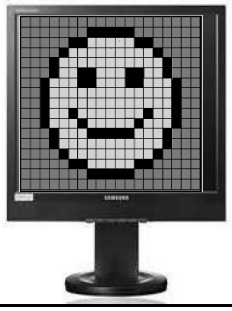
Data logic (File) – da li se komponovani grafički sadržaj trajno čuva kao skup tačaka (bmp, tiff, jpeg, raw, png, ...) ili vektora (cdr, svg, ai, …).

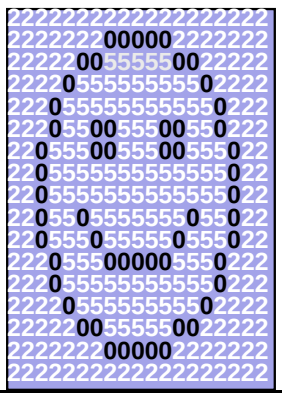
Šta je sa *.wmf?

Koji fajl ide sa kojim SW?

Razmena?

8 level gray





```
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"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)

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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

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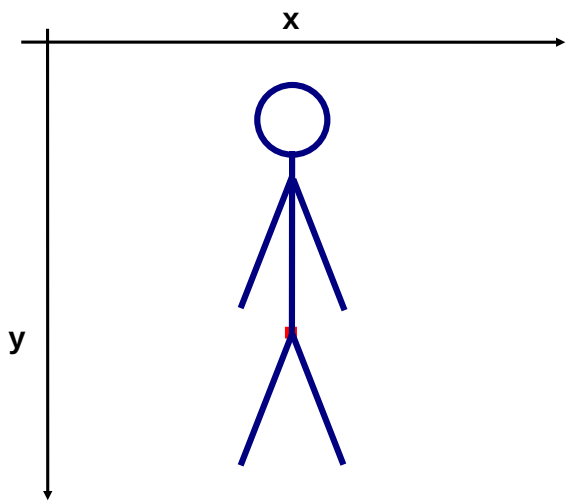
Dizajniramo



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)

Tok aktivnosti prikaza na vektorskom HW

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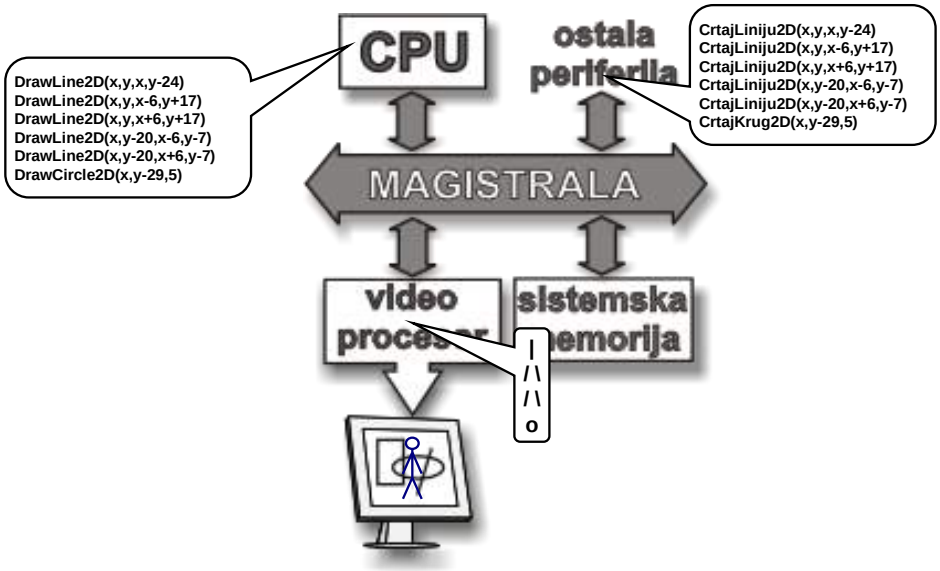

HW arhitektura rasterskog HW bez GPU

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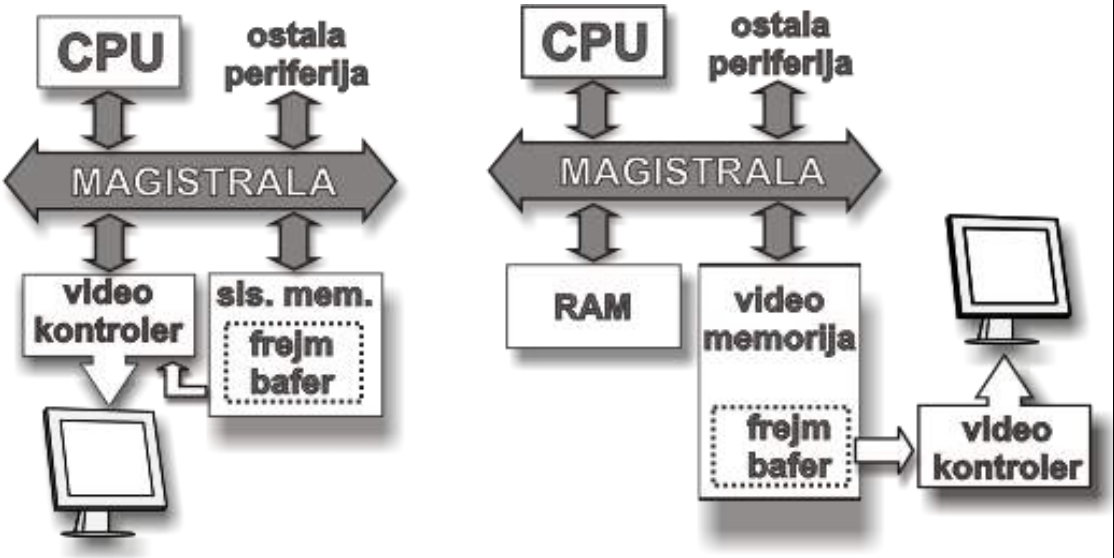

- **Arhitektura sa deljenom memorijom.**
- **Arhitektura sa izolovanom memorijom.**

Tok aktivnosti prikaza na rasterkom HW bez GPU

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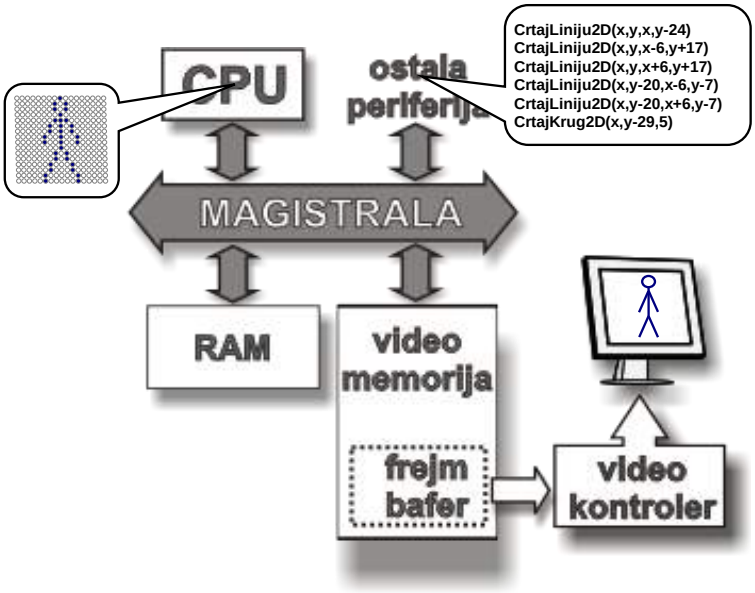

HW arhitektura rasterskog HW sa GPU

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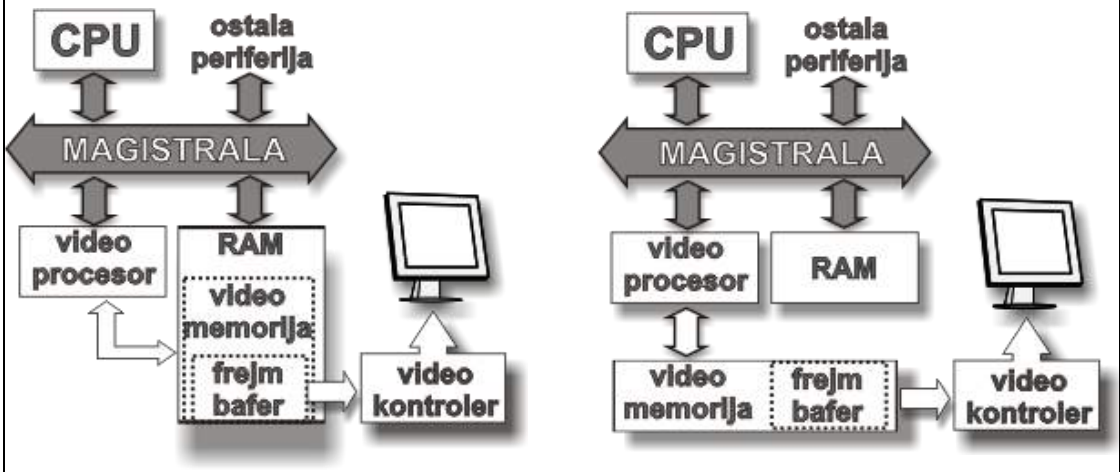

- **Arhitektura sa deljenom memorijom.**
- **Arhitektura sa izolovanom memorijom.**

Tok aktivnosti prikaza na rasterskom HW sa GPU

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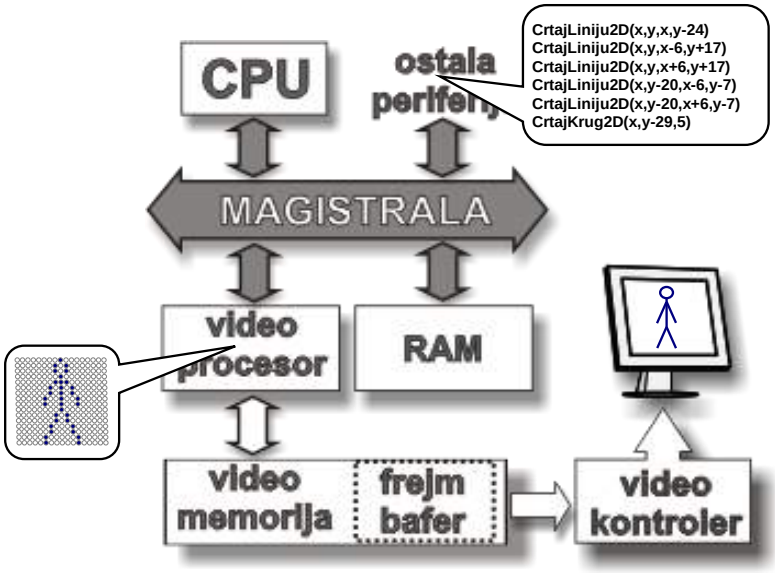

Video kontroler klasične arhitekture

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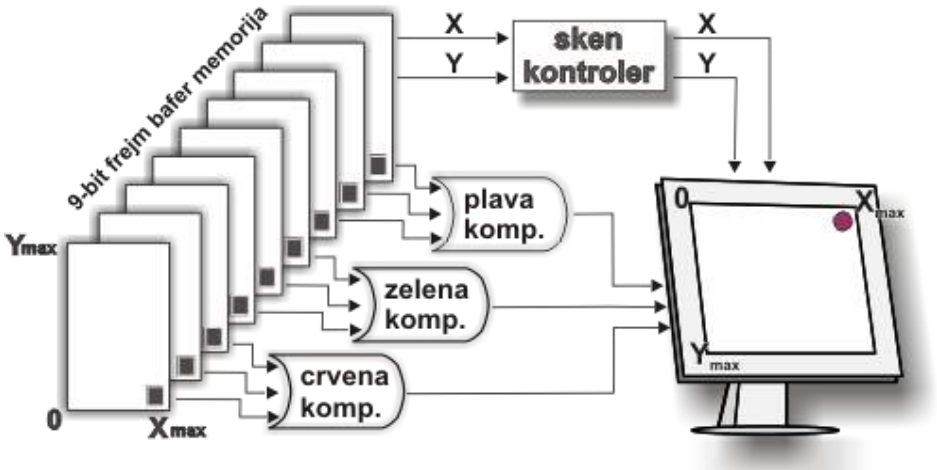

- za prikaz od 1024x1280 piksela i sa true-colour sistemom, 2^{24} boja,
  - veličina frejm bafera: 1.310.720 x 3 bajta = 3,75 Mbajta.

Video kontroler LookUpTable arhitekture

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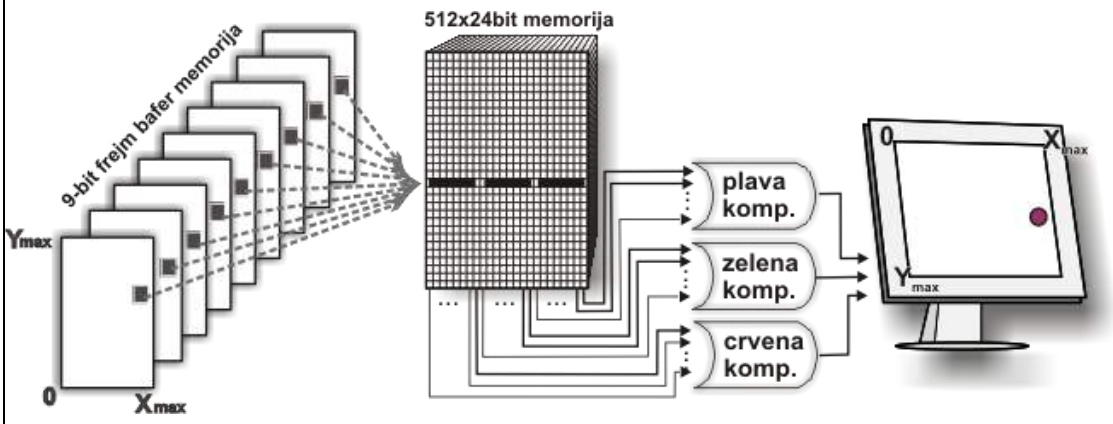

- **LUT – progr. sadržaj, 512 paleta od mogućih 2^{24} boja,**
- **Kolika je razlika u angažovanoj memoriji za prikaz od 1024x1280 piksela i sa 2^{24} boja, sa i bez LUT tabele?**
- **Koja arhitektura kontrolera je bolja? Zašto?**
- **Koji format grafičkog fajla odgovara ovom kontroleru?**

HW arhitektura grafičke aplikacije

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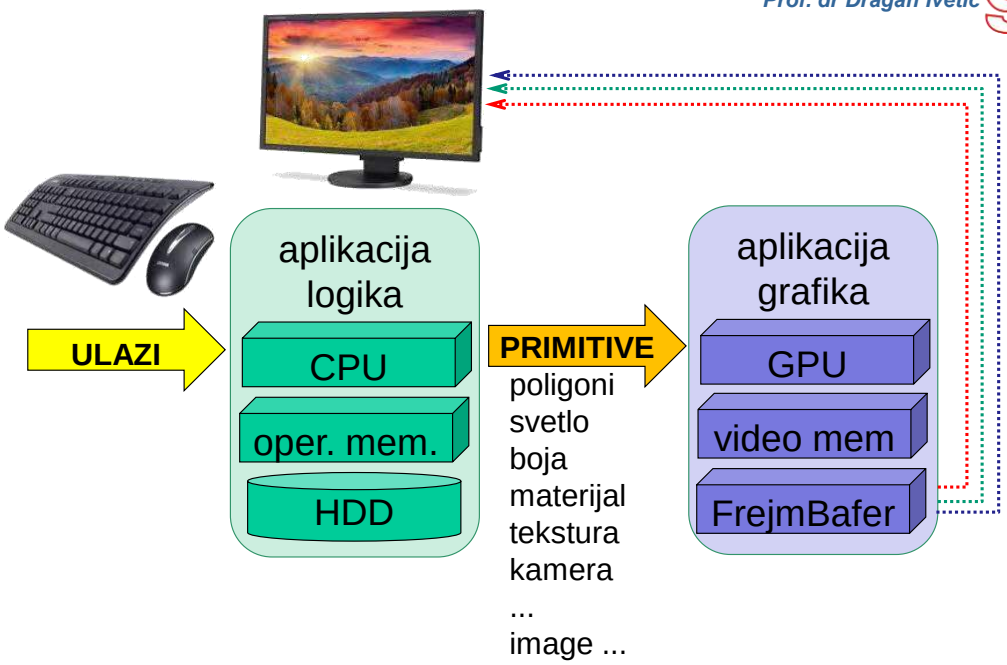
Prof. dr Dragan Ivetić



za trenutno stanje interakcije

Osnove grafičkog pajplajna (pipeline)

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- **prisetite se kreiranja kocke na stolu,**
- **mi smo uradili sledeće aktivnosti:**
  kocka i sto kao: tačke/linije/trouglovi, projekcija/skrivanje, bojili, senčili, tekstura i blending..

- **sekvenca koraka u kreiranju 2D prikaza neke 3D scene!**

- **zašto cevovod (pipeline)?**
  - **sekvencijalna priroda u osnovi (tok jedne u drugu, mešaju se),**
  - **kraj/početak etape nije uvek diskretan (jasan),**
  - **složenija 3D scena onda i prečnik mora da ...**
  - **šta raditi ako samo neka etapa traži više obrade (manji protok) a opet zadržati isti protok u ostalim etapa kreiranja 2D prikaza neke 3D scene?**

Grafički pajplajn (istraživačko/edukativni) ...

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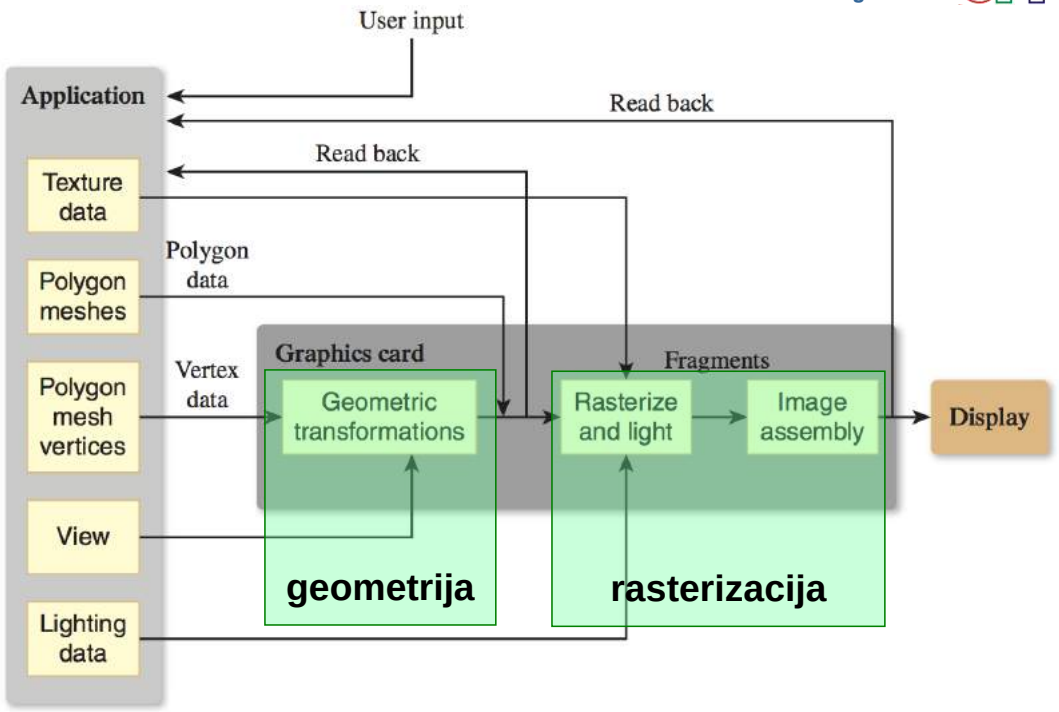

Grafički pajplajn ... (istraživačko/edukativni) ...

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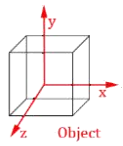
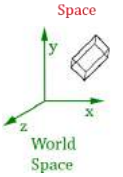
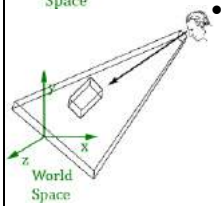
GEOMETRIJA

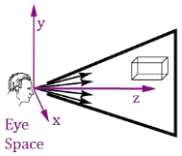
Model&View *Transform* → **Vertex *Shading*** → **Projection** → **Clipping** → **Screen *Mapping***

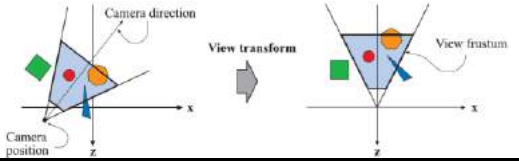


- 3D scena komponovana instanciranjem modela (objekata)
- svaki model sa svojim atributima i koord. sistemima,
  - transformacijom se model postavlja na poziciju u world coordinates (space) – scena,
    - na koji korisnik gleda iz neke tačke scene "kroz kameru" što se zove camera (eye) space,
  - view transform mapira world coordinates u svoj sistem da bi olakšala naredne aktivnosti…









Grafički pajplajn
... (istraživačko/edukativni) ...

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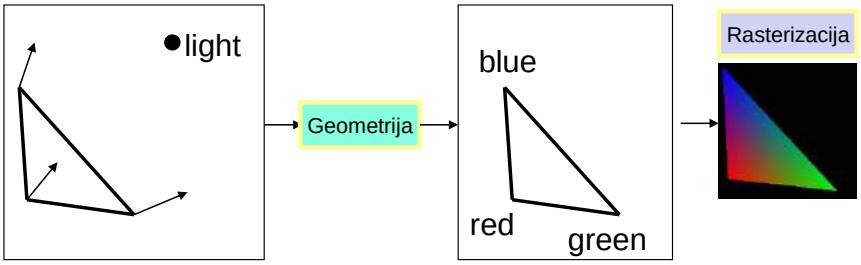
GEOMETRIJA

Model&View *Transform* → **Vertex *Shading*** → **Projection** → **Clipping** → **Screen *Mapping***

- **pored samog oblika objekata, prikazati materijal objekta i kontekst sredine gde se objekt nalazi – shading,**
- **određivanje svetlosne jednačine na nivou temena spremajući za rasterizaciju i pixel shading…**
- **nemoguće kreirati ili ukloniti teme, ali može podatke koji su pridruženi temenu,**



Grafički pajplajn
... (istraživačko/edukativni) ...

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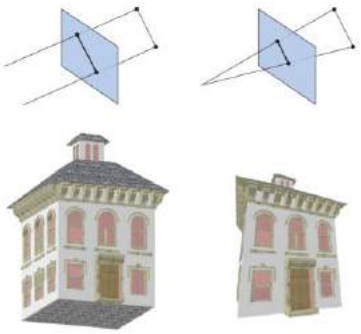
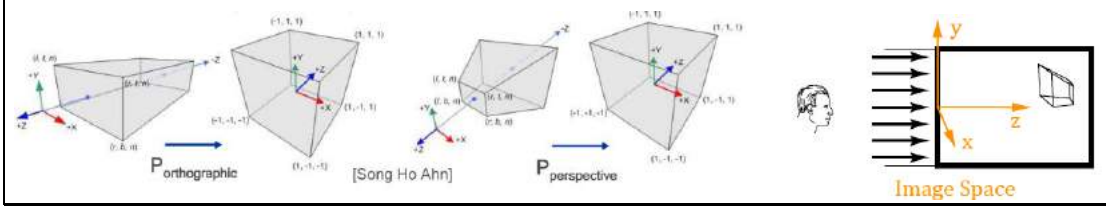
GEOMETRIJA

Model&View *Transform* → **Vertex *Shading*** → **Projection** → **Clipping** → **Screen *Mapping***

- **paralelna ili perspektivna projekcija na view volume (unit cube),**
- **često je "uparalelizovana" sa narednom fazom,**
- **model je sada definisan u normalized device coordinates – image space,**





Grafički pajplajn
... (istraživačko/edukativni) ...

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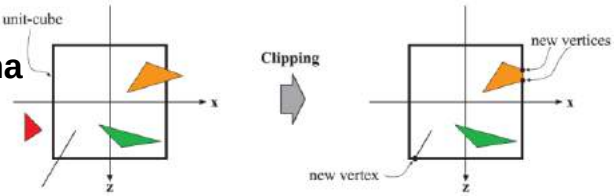
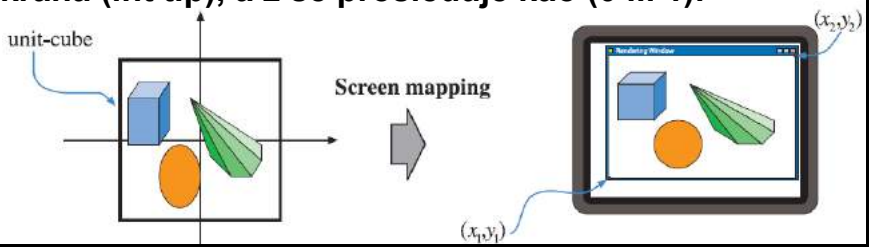
GEOMETRIJA

Model&View *Transform* → **Vertex *Shading*** → **Projection** → **Clipping** → **Screen *Mapping***

- **veličina 3D scene postaje invarijantna na mogućnosti prikaza,**
- **u unit cube stoje zahvaćena temena i novonastala temena koja su nastala isecanjem primitiva.**



- **x i y koordinate temena u/na unit cube, preslikavaju se u koordinate ekrana (int tip), a z se prosleđuje kao (0 ... 1).**



Grafički pajplajn
... (istraživačko/edukativni) ...

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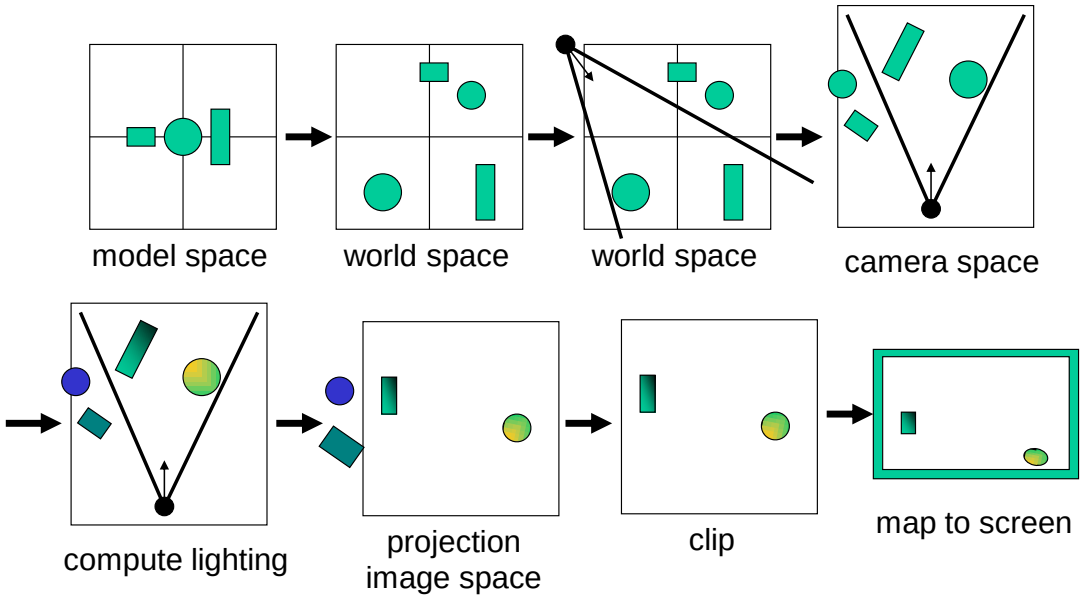
GEOMETRIJA ilustrativno kako to vidi Tomas Akenine-Mőller



Grafički pajplajn
... (istraživačko/edukativni) ...

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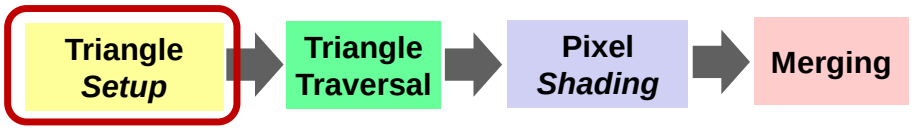
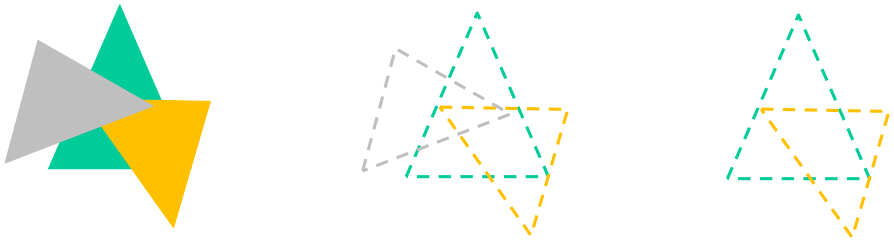
RASTERIZACIJA (ili scan conversion) da 2D temena (sa pridruž. *z* vrednošću i različitim shading info) u piksele na ekranu,



- **sračunava (diferencijale ivica trouglova) podatke interesantne za određivanje površine u narednim fazama (pre svega scan conversion), obavlja fiksirano-operacioni hw moduli GPU,**
- **potom "backface culling" pa trouglovi koji nisu uništeni idu u narednu fazu - triangle traversal**



Grafički pajplajn
... (istraživačko/edukativni) ...

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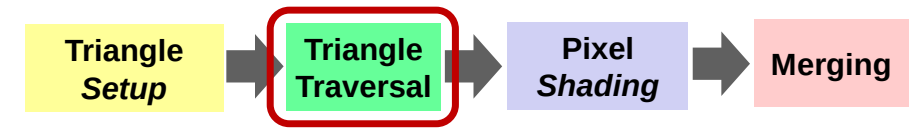
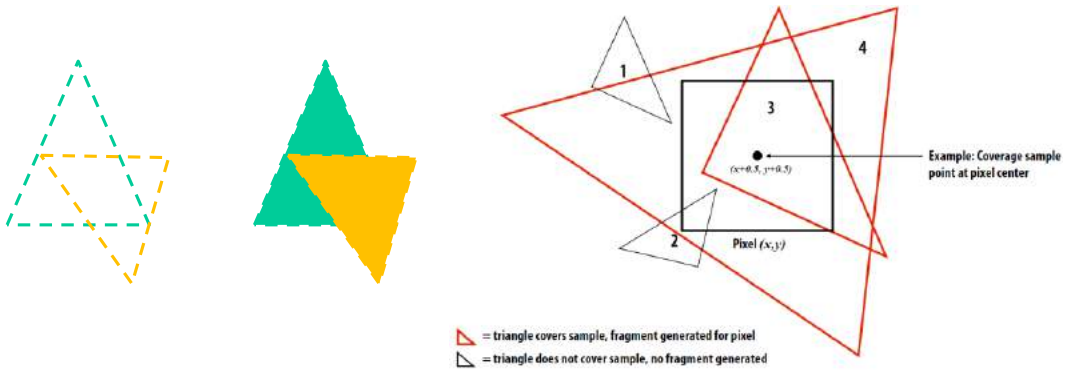
RASTERIZACIJA



- **ili scan conversion - formira fragmente (set of samples/pixels) od kojih se sastoji površina trougla,**
- **održava sve ostale podatke o fragmentu iz geometrije (Z, boje...),**



Grafički pajplajn
... (istraživačko/edukativni) ...

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RASTERIZACIJA

Triangle *Setup* → Triangle Traversal → Pixel *Shading* → Merging

- **sračunava konačnu boju fragmenta zavisno od izvora svetla, boje, materijala...**
- **izvšava (krajnje programabilna) jezgra GPU,**
- **komplikovano i zasnovano na mnoštvu ulaznih podataka,**
- **rezultat je samo vrednost boje,**
- **osnovne operacije su: texturing i per pixel lighting.**

Grafički pajplajn
... (istraživačko/edukativni)

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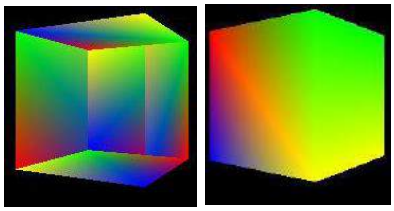
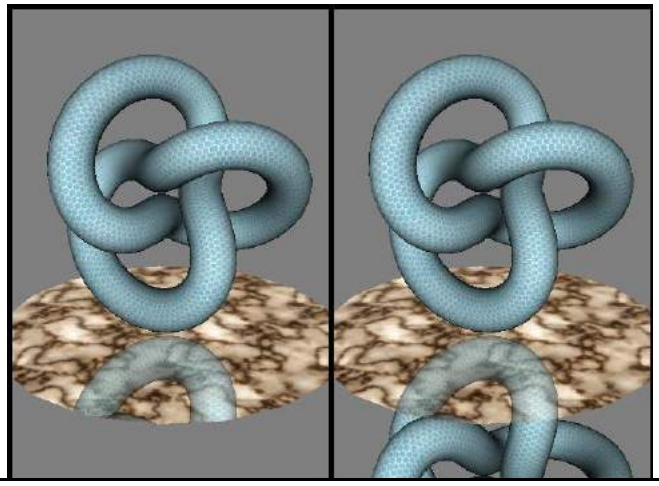
RASTERIZACIJA

Triangle *Setup* → Triangle Traversal → Pixel *Shading* → Merging

- **konačno uređuje frejm bafer za prikaz kombinujući (blending) osnovni kolor bafer sa bojom fragmenta i Z baferom,**





- **ali i sa stencil baferom,**
- **i alpha baferom.**

Grafički pajplajn

... u praksi ...

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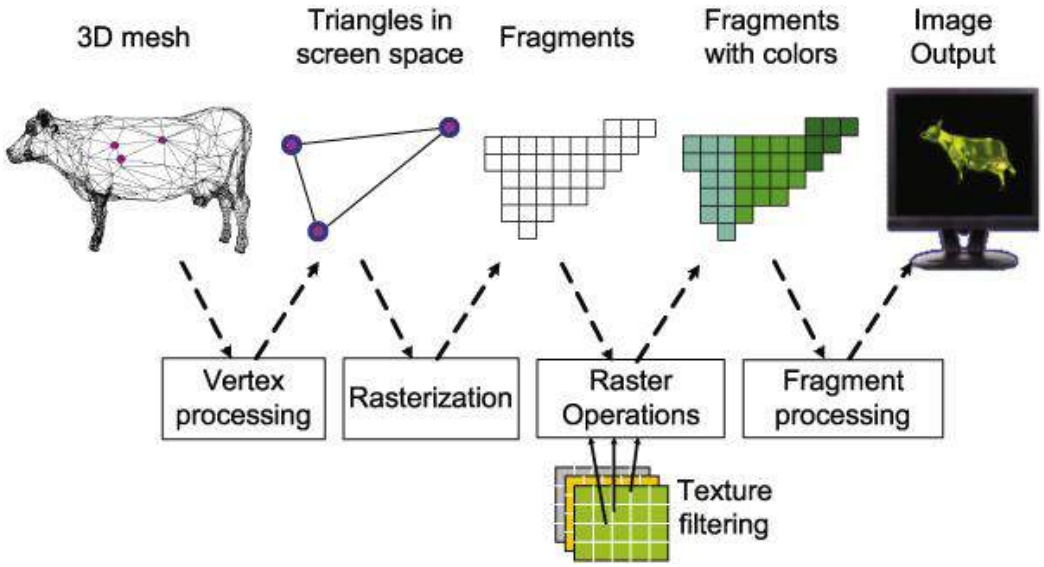
Slikoviti pajplajn



Grafički pajplajn

... u praksi ...

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Ko izvršava aktivnosti grafičkog i rasterskog dela pajplajna?

Do 1995. godine –
CPU softversko renderovanje grafike
(prvo 2D, pa i 3D do 1995.),

1996. godine
prvi GPU automatizuje najjednostavnije procese pajplajna:
mapiranje teksture i Z-bafer

(3dfx Voodoo 1996.),

Grafički pajplajn

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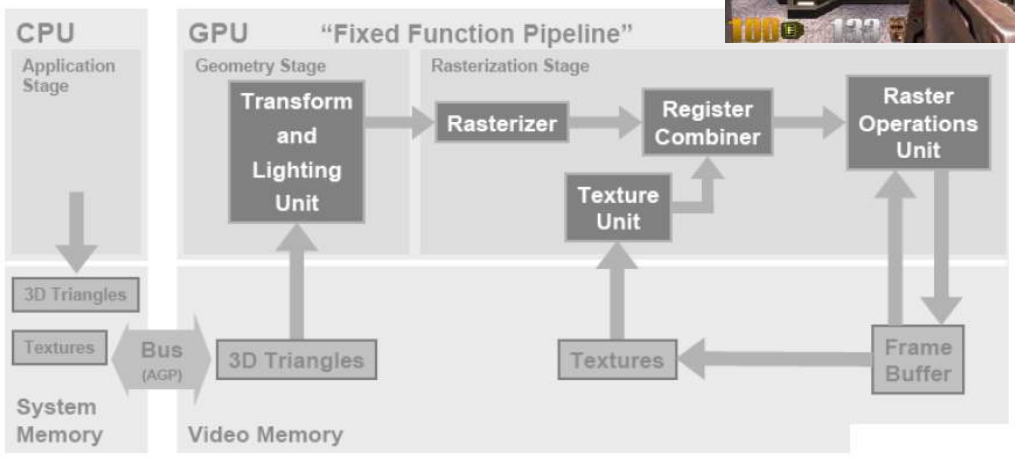
... u praksi ...

1998. Godine

GPU fiksne funkcije – obezbeđuje sve aktivnosti pajplajna kroz parametrizovane pozive



- Register Combiner: Offers many more texture/color combinations
- NVIDIA's GeForce 256 and GeForce2, ATI's Radeon 7500, S3's Savage3D

Grafički pajplajn

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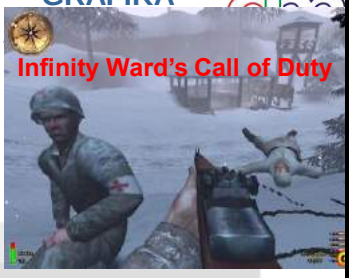
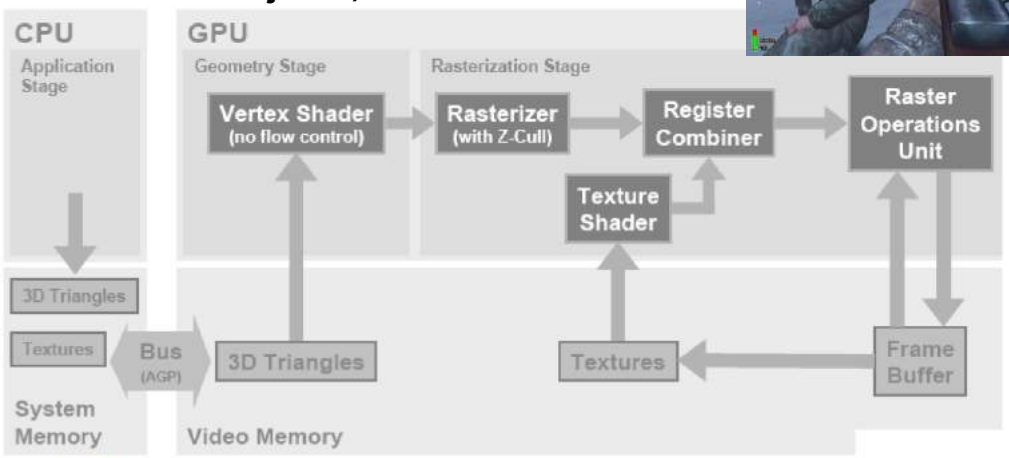
... u praksi ...



Od 2001. – 2002. godine

GPU program. funkcije statičnog toka – obezbeđuje izvršavanje programskog koda verteks šejdera,



- Z-Cull: Predicts which fragments will fail the Z test and discards them
- Texture Shader: Offers more texture addressing and operations
- NVIDIA's GeForce3 and GeForce4 Ti, ATI's Radeon 8500

Grafički pajplajn

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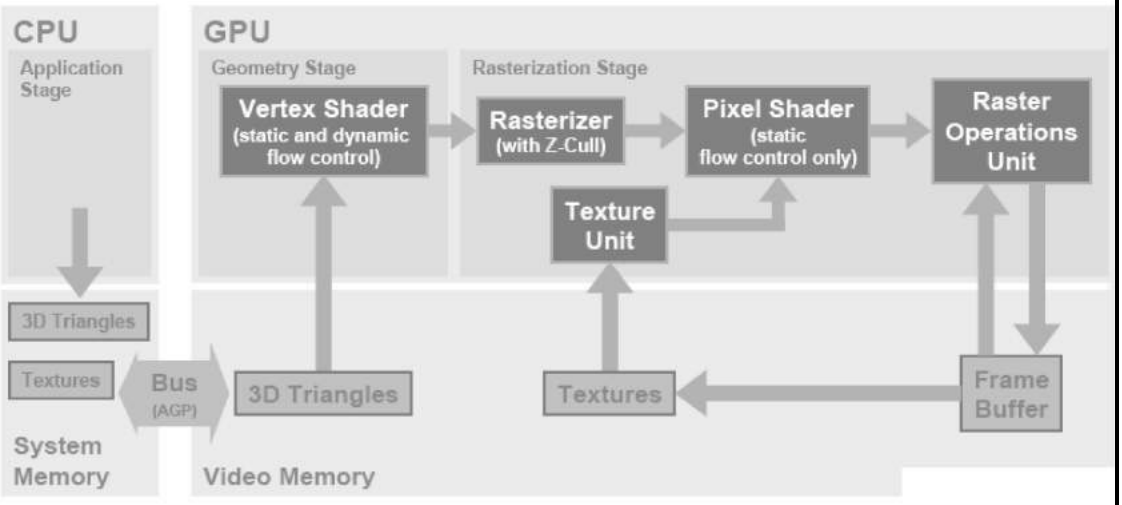
... u praksi ...

Od 2003. – 2004. godine

GPU program. funkcije dinamičkog toka

verteks i piksel (statički) šejderi



- MRT: Multiple Render Target
- NVIDIA's GeForce FX, ATI's Radeon 9600 to 9800 and X600 to X800

Grafički pajplajn

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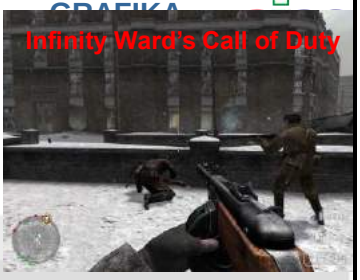
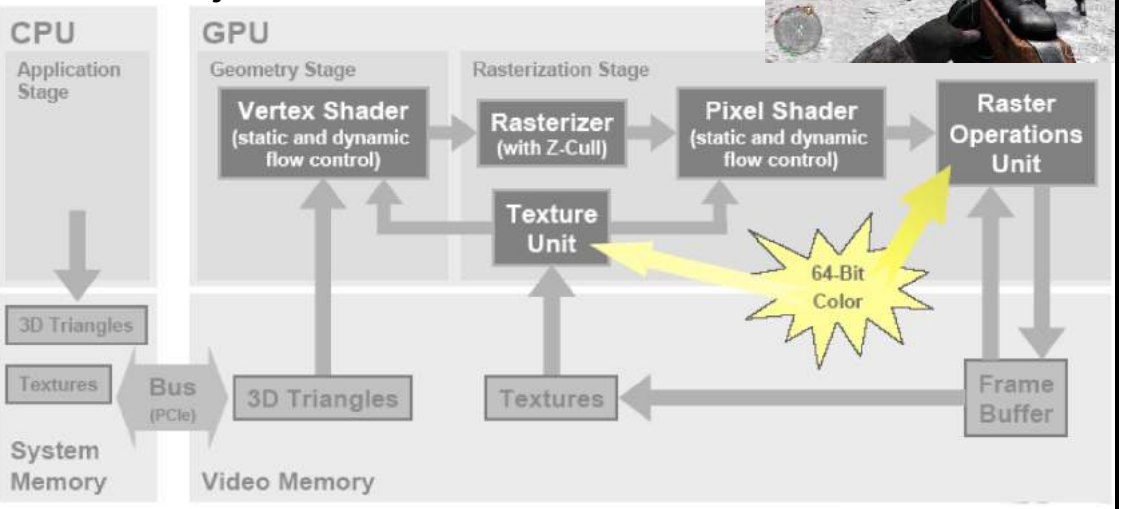
... u praksi ...

Od 2004. – 2006. godine

GPU program. funkcije dinamičkog toka

sa šejder modelom 3.0





- PCIe: Peripheral Component Interconnect Express
- NVIDIA's GeForce 6 Series (6800 and 6600)

Grafički pajplajn

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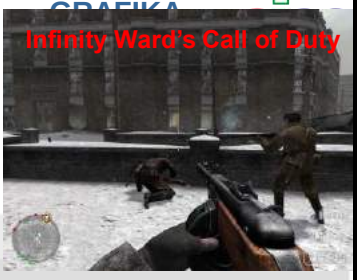
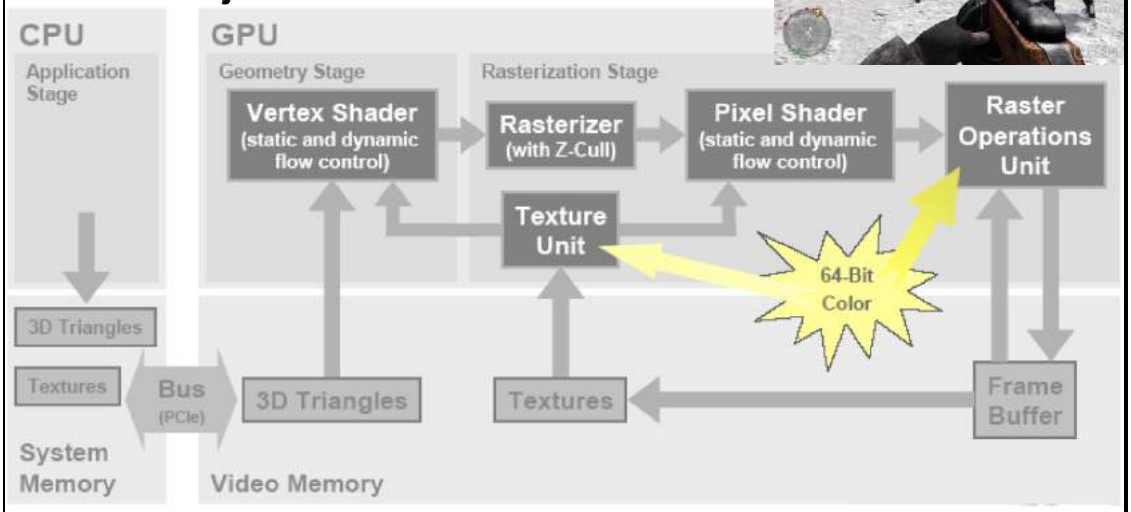
... u praksi ...



Od 2004. – 2006. godine

GPU program. funkcije dinamičkog toka

sa šejder modelom 3.0



- PCIe: Peripheral Component Interconnect Express
- NVIDIA's GeForce 6 Series (6800 and 6600)

Grafički pajplajn

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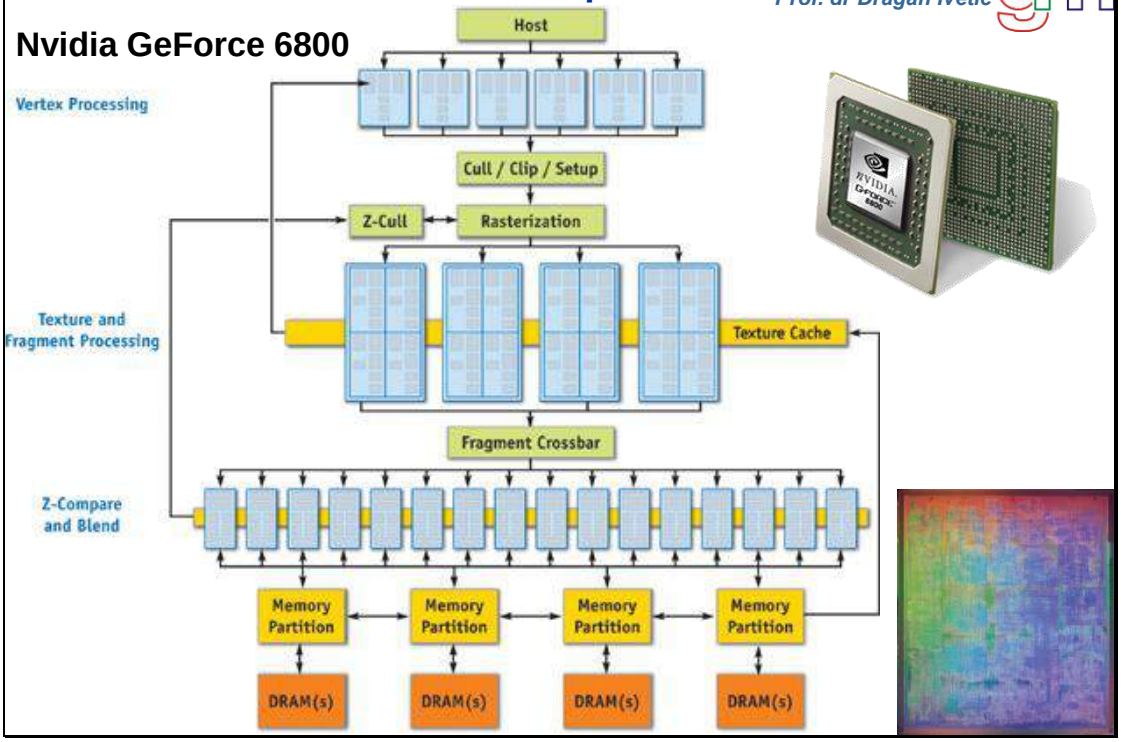
... u praksi ...

Nvidia GeForce 6800



Grafički pajplajn

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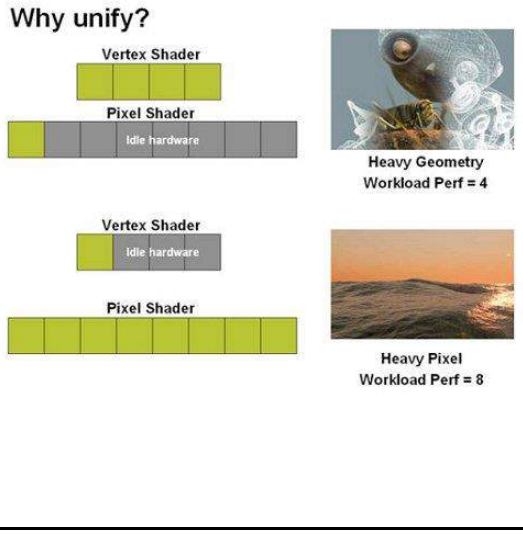
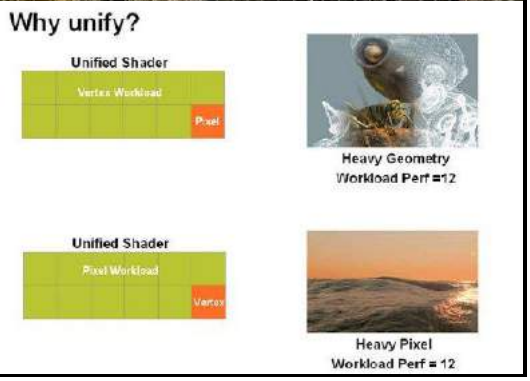
... u praksi ...

Od 2006. godine

GPU programabilne funkcije unificirani šejderi različitih vrsta (GeForce 8).





Grafički pajplajn

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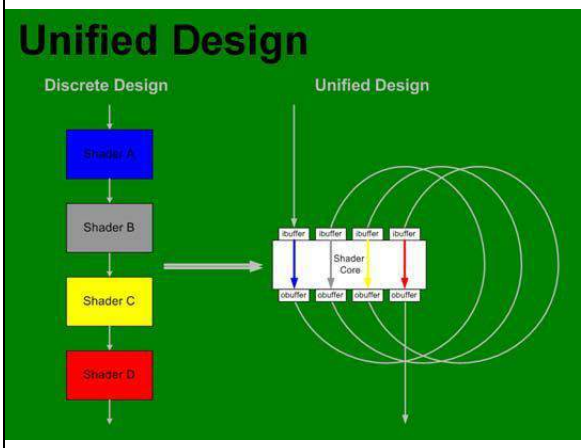
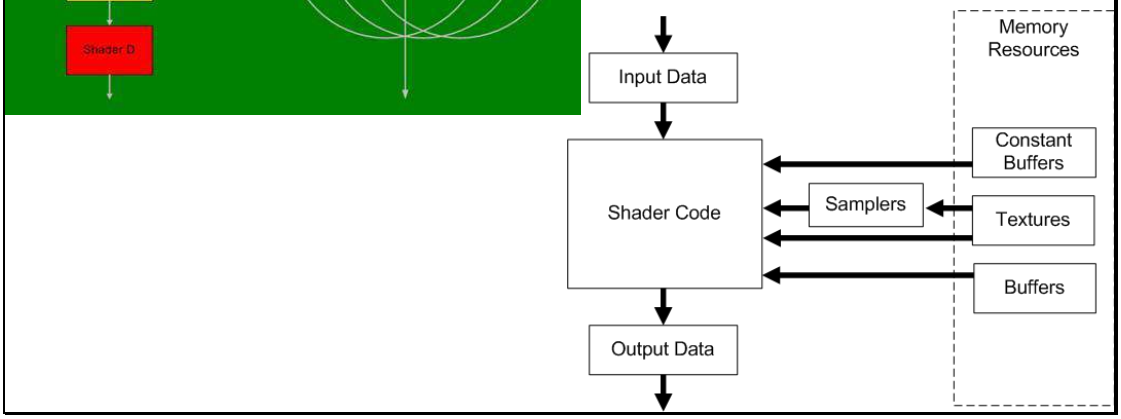
... u praksi ...





Grafički pajplajn

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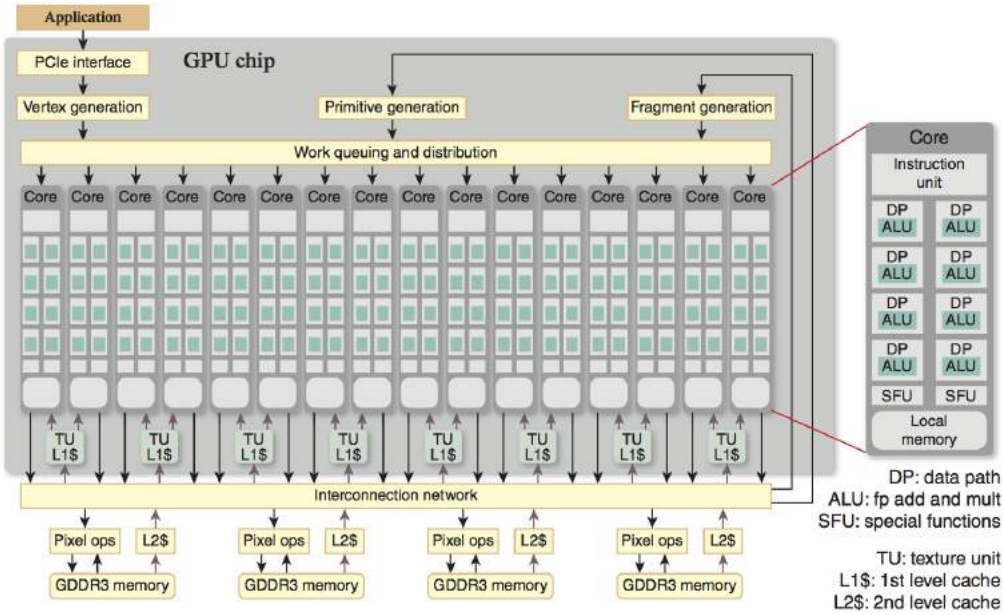
... u praksi ...

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



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

Grafički pajplajn

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... u praksi ...

2010./2011. CRYTEK's Cryengine3.

NVIDIA Geforce GTX580
Interface: PCIe 2.0 x16
Shader Model: 5.0
DirectX: 11
Manufacturing Process: 40 nanomet
Core Clockspeed: 770MHz
Memory Amount: 1536MB
Memory Clockspeed: 2004MHz
Memory Bus: 384-bit
Transistors: 3 billion

16 stream multiprocessors
32 CUDA procesora (ALU+FPU)
4 SFU)

Grafički pajplajn

... u praksi ...

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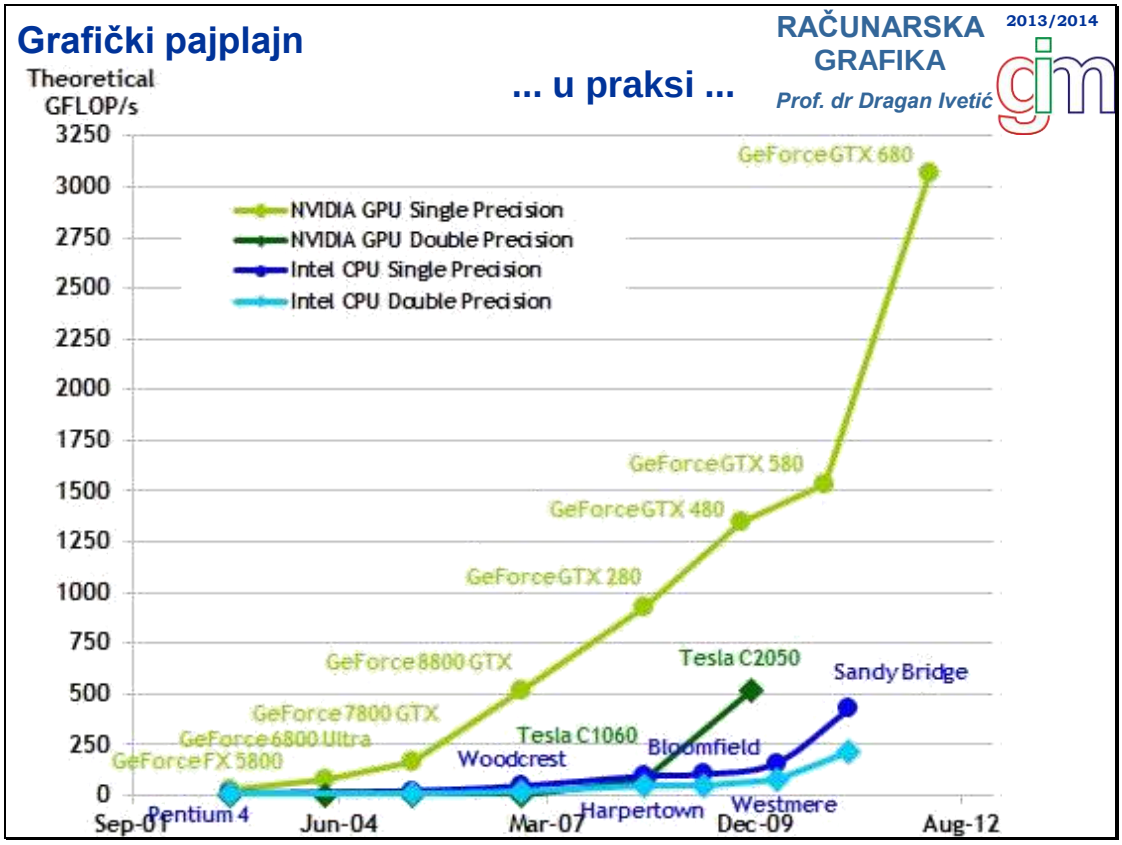

Grafički pajplajn

... u praksi

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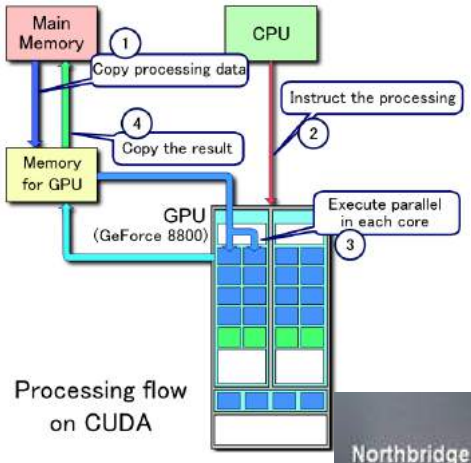

Programske biblioteke

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- softverski interfejs ka grafičkom hardveru (API)
- najviše korišteni su:

- grafička biblioteka raspoloživa za sve SW/HW platforme: od Unix, Sun, HP, Microsoft, Apple, Android do ugradnih sistema,
- poveziv sa svim značajnijim jezicima: Ada, Basic, C#, Fortran, Java, Pascal, Perl, Python, Ruby...
- koristi se za svaki posao gde i računarska grafika...

- Direct3D za podršku grafike unutar DirectX ,
- samo pod Microsoft (Xbox),
- MS COM baziran: Delphi, MS Visual C++, C#, VB .NET (ostali indirektno)...
- uglavnom igrice...

- sw/hw proizvođači prate promene u DirecX dok OpenGL ide posle...

OpenGL ...

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- SGI prvo razvio Integrated Raster Imaging System Graphics Library, 2D/3D API za IRIX grafičke stanice 1988. godine,
- IRIS GL nije bio formalno specifikovan i usaglašen, pa 1992. SGI krenuo u definisanje otvorenog standarda (i za druge platforme) OpenGL1.0,
  - ustanovljen OpenGL Architecture Review Board (SGI, DEC, IBM, Intel i Microsoft),

1997. donet OpenGL 1.1 koji je uneo pre svega `glBindTexture`,
1998. OpenGL 1.2 uveo rad sa slikama i 3D texture..,
2001. OpenGL 1.3 - multiteksture i kompresovane teksture...,
2002. OpenGL 1.4 – fog, stencil, window raster position ....,
2003. OpenGL 1.5 – buffer object, occlusion, shadow ...., MS out!
2004. OpenGL 2.0 – osnove verteks šejdera i GLSL jezika,
2006. OpenGL 2.1 – piksel bafer i specifikacija GLSL 1.2 ....,
pao SGI pa i ARB, preuređen u Khronos grupu,
2008 - 3.0, 2009. – 3.1 i 3,2, 2010. – 3.3,
2010. – 4.0 i 4.1, 2011. – 4.2, 2012. – 4.3, 2013. – 4.4.

... OpenGL ...

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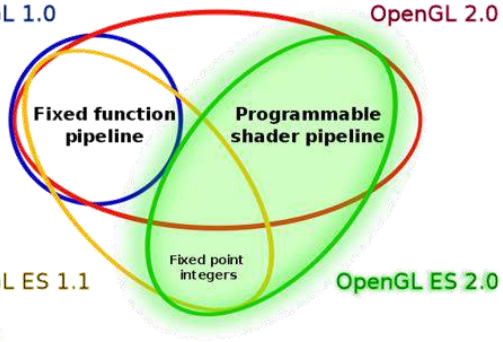
izvedeni standardi: OpenGL ES

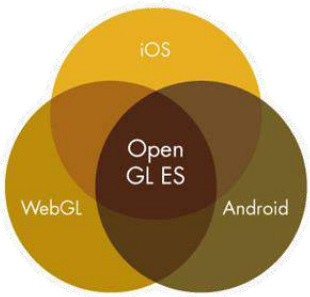
1.OpenGL for Embedded Systems – podskup OpenGL 3D API za ugradne sisteme – mobilni (Android,iOS), PDA, video game konzole...

- pojednostavljeni tipovi i sintaksa – glbegin,
- dve različite verzije.



2.OpenGL for the Web WebGL

- obezbeđuje GPU podržanu 3D grafiku na web stranici,
- HTML5 canvas element i javascript,
- diskutabilna podržanost od strane web klijenata,
- moguće mesto upada.



... OpenGL ...

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... OpenGL ...

Khronos Visual Computing Ecosystem

Authoring and accessibility

- COLLADA — 3D Digital Asset Exchange format
- WebGL — Plugin-free 3D Web Content
- WebCL — Web Compute
- StreamInput — Unified Sensor and Input Processing

Application Acceleration

- OpenGL — Cross platform desktop 3D
- OpenCL — Parallel Computing
- OpenGL|ES — Embedded 3D
- EGL — Context, Sync and Surface Management
- OpenGL|SC — Safety Critical 3D
- OpenMAX|AL — Rich Media Framework
- OpenSL|ES — Advanced Audio
- OpenVG — Vector 2D

System Integration

- OpenMAX|IL — Video, Audio, Image Component Integration
- OpenMAX|DL — Codec Creation
- OpenWF — Window System Acceleration

teme za diplomske radove

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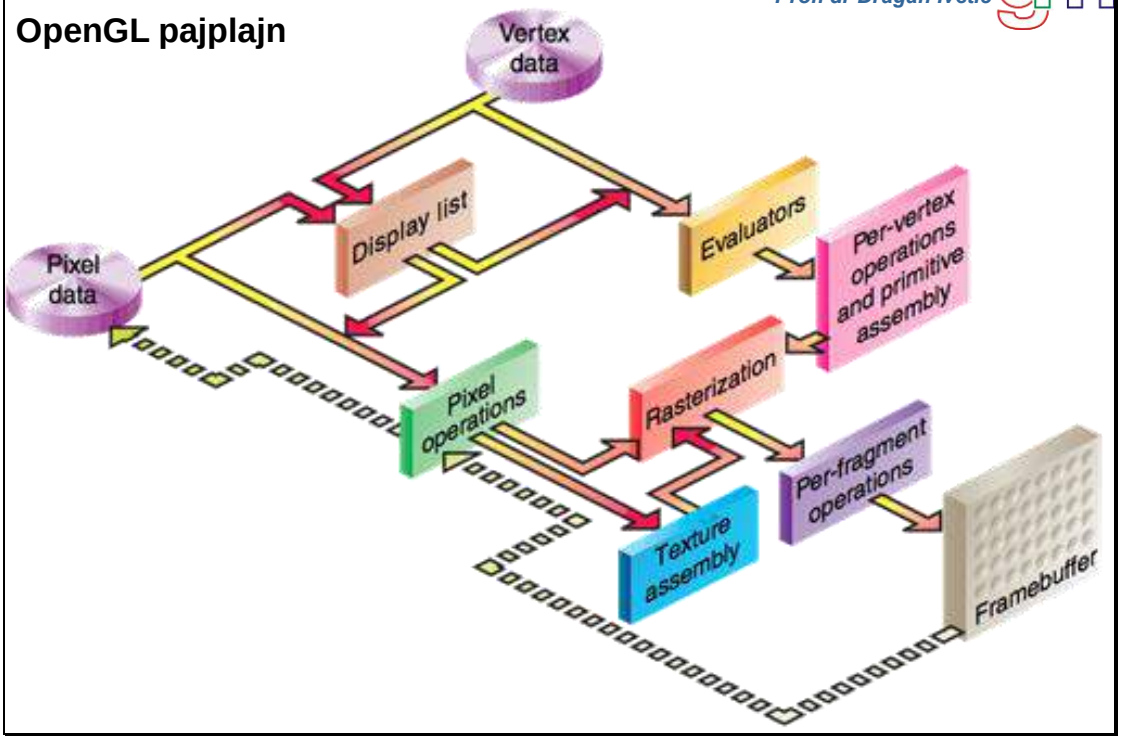
... OpenGL ...

OpenGL pajplajn



... OpenGL ...

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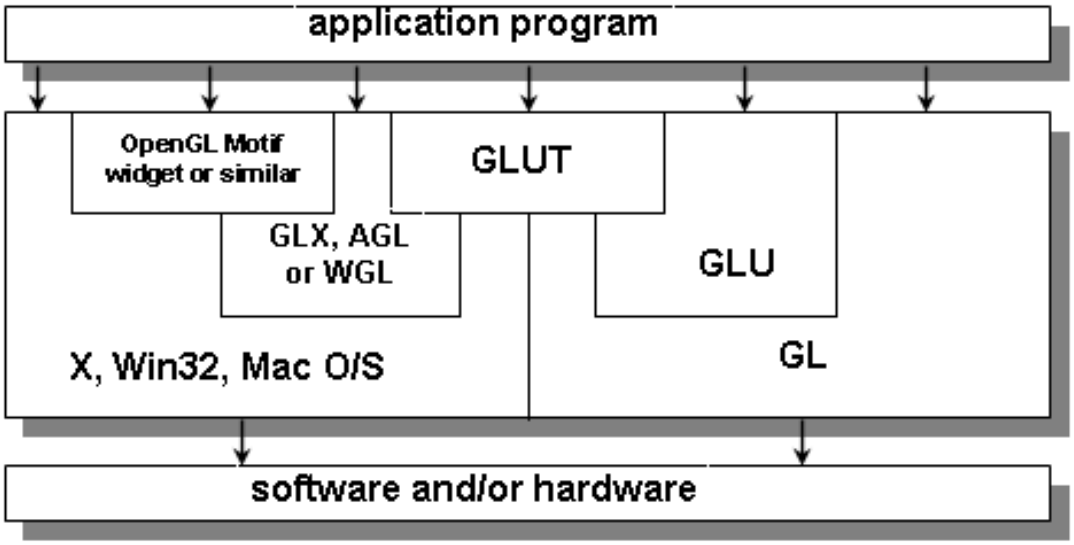
softverska arhitektura



... OpenGL

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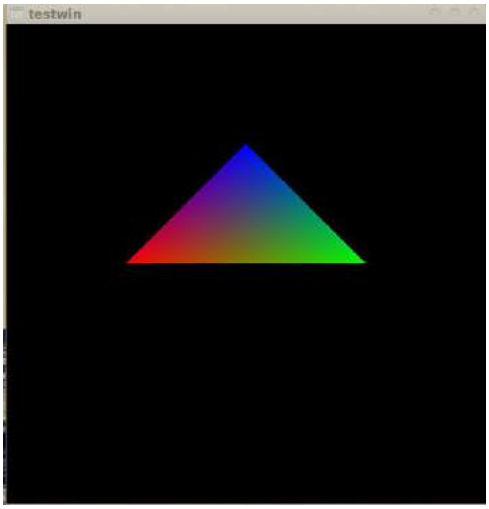
```
#include "stdio.h"
#include "GL/glut.h"

void render()
{               glBegin(GL_TRIANGLES);
                        glColor3f(  1.0, 0.0, 0.0);
                        glVertex3f(-0.5, 0.0, 0.0);
                        glColor3f(  0.0, 0.0, 1.0);
                        glVertex3f( 0.0, 0.5, 0.0);
                        glColor3f(  0.0, 1.0, 0.0);
                        glVertex3f( 0.5, 0.0, 0.0);
                glEnd();

                glutSwapBuffers();

                return;}

int main(int argc, char **argv)
{
        glutInit(&argc, argv);
        glutInitWindowPosition(100,100);
        glutInitWindowSize(500,500);
        glutInitDisplayMode(GLUT_RGBA | GLUT_DOUBLE);
        glutCreateWindow("testwin");

        glutDisplayFunc(render);
                glutMainLoop();
                return 0;}
```



Direct3D ...

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- **Direct3D je grafička komponenta DirectX kolekcije API-ja za podršku multimediji,**

- **MS otkupio Reality Lab 3D API 1992. i ugradio u Win95 kao 3D engine, posle Win. games SDK, pa ugrađeno u DirectX 2.0 i 3.0,**
  - **execute buffer – parsiran od strane HW da bi prikazao scenu,**

DirectX 5.0 (97) i 5.2 (98) isključio execute bafer sa Draw API,
DirectX 6.0 (98) i 6.1 (99) optimizovao geometrijski pajplajn za x87,
DirectX 7.0 (99) i 7.1 (00) hardversko ubrzanje transformacija i osvetljenja sa Nvidia GeForce familijom GPU,
DirectX 8.0 (00), 8.1 (01) i 8.2 (02) programabilni šejderi,
DirectX 9.0 (03) i 9.0abc (svaka 2 meseca do juna 10) novi HLSL,
DirectX 10.0 (06) i 10.1 (08) novi šejder model 4.0 za Vistu, pajpalajn fiksne funkcije isključen
DirectX 11.0 (09) i 11.1 (12) tessellation za Windows 7, odnosno Windows 8, quad bauffering.

... Direct3D ...

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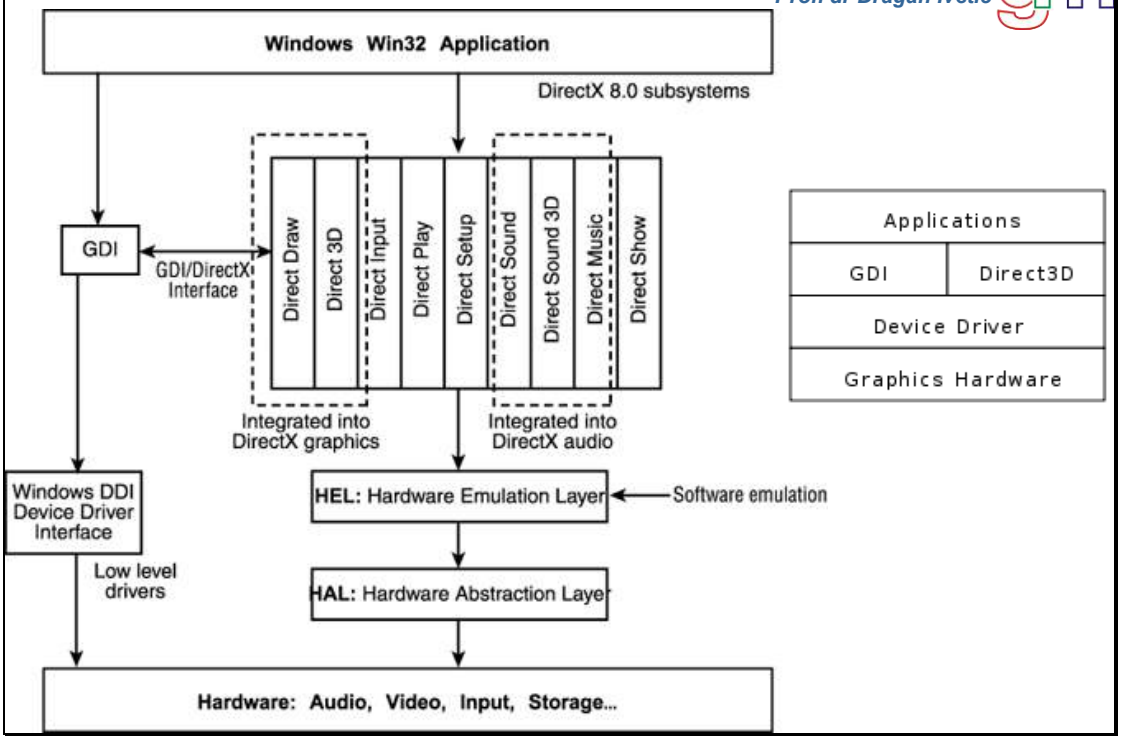

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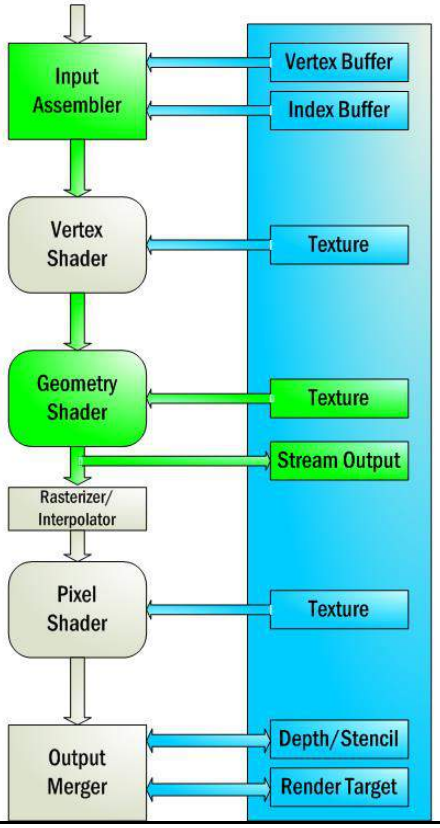
Direct3D pajplajn



... Direct3D ...

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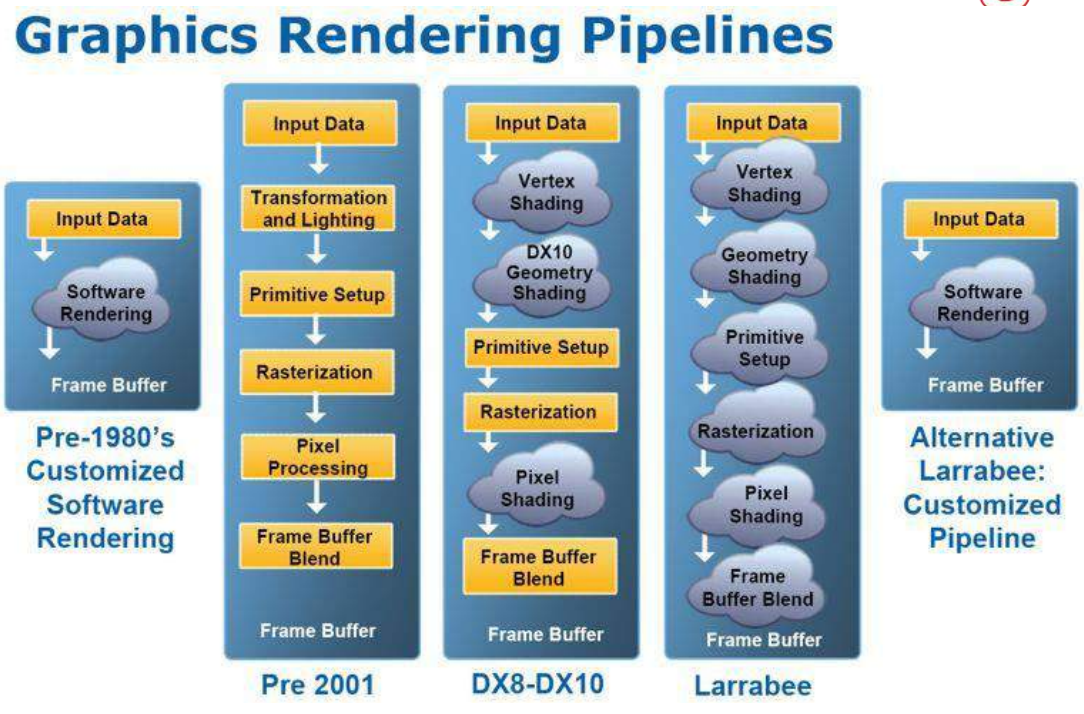

... Direct3D ...

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DirectX9
Lesson 4: Drawing a Triangle
http://www.directxtutorial.com

```
// include the basic windows header files and the Direct3D header file
#include <windows.h>
#include <windowsx.h>
#include <d3d9.h>

// define the screen resolution
#define SCREEN_WIDTH 800
#define SCREEN_HEIGHT 600

// include the Direct3D Library file
#pragma comment (lib, "d3d9.lib")

// global declarations
LPDIRECT3D9 d3d;    // the pointer to our Direct3D interface
LPDIRECT3DDEVICE9 d3ddev;    // the pointer to the device class
LPDIRECT3DVERTEXBUFFER9 v_buffer = NULL;    // the pointer to the vertex buffer

// function prototypes
void initD3D(HWND hWnd);    // sets up and initializes Direct3D
void render_frame(void);    // renders a single frame
void cleanD3D(void);    // closes Direct3D and releases memory
void init_graphics(void);    // 3D declarations

struct CUSTOMVERTEX {FLOAT X, Y, Z, RHW; DWORD COLOR;};
#define CUSTOMFVF (D3DFVF_XYZRHW | D3DFVF_DIFFUSE)

// the WindowProc function prototype
LRESULT CALLBACK WindowProc(HWND hWnd, UINT message, WPARAM wParam, LPARAM lParam);
```

... Direct3D ...

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```
// the entry point for any Windows program
int WINAPI WinMain(HINSTANCE hInstance, HINSTANCE hPrevInstance, LPSTR lpCmdLine, int nCmdShow)
{  HWND hWnd;
   WNDCLASSEX wc;

   ZeroMemory(&wc, sizeof(WNDCLASSEX));

   wc.cbSize = sizeof(WNDCLASSEX);                    wc.style = CS_HREDRAW | CS_VREDRAW;
   wc.lpfnWndProc = WindowProc;                       wc.hInstance = hInstance;
   wc.hCursor = LoadCursor(NULL, IDC_ARROW);          wc.lpszClassName = L"WindowClass";
   RegisterClassEx(&wc);

   hWnd = CreateWindowEx(NULL, L"WindowClass", L"Our Direct3D Program", WS_OVERLAPPEDWINDOW
                         0, 0, SCREEN_WIDTH, SCREEN_HEIGHT, NULL, NULL, hInstance, NULL);

   ShowWindow(hWnd, nCmdShow);

  // set up and initialize Direct3D
   initD3D(hWnd);

   // enter the main loop:
   MSG msg;
   while(TRUE)
   {while(PeekMessage(&msg, NULL, 0, 0, PM_REMOVE))
      {  TranslateMessage(&msg);
         DispatchMessage(&msg); }

      if(msg.message == WM_QUIT) break;

      render_frame(); }

   // clean up DirectX and COM
   cleanD3D();

   return msg.wParam; }
```

... Direct3D ...


```
// this is the main message handler for the program
 LRESULT CALLBACK WindowProc(HWND hWnd, UINT message, WPARAM wParam, LPARAM lParam)
{ switch(message)
   { case WM_DESTROY: { PostQuitMessage(0); return 0; }
     break;}
   return DefWindowProc (hWnd, message, wParam, lParam);}


// this function initializes and prepares Direct3D for use
void initD3D(HWND hWnd)
{
   d3d = Direct3DCreate9(D3D_SDK_VERSION);

   D3DPRESENT_PARAMETERS d3dpp;

   ZeroMemory(&d3dpp, sizeof(d3dpp));                  d3dpp.Windowed = TRUE;
   d3dpp.SwapEffect = D3DSWAPEFFECT_DISCARD;           d3dpp.hDeviceWindow = hWnd;
   d3dpp.BackBufferFormat = D3DFMT_X8R8G8B8;           d3dpp.BackBufferWidth = SCREEN_WIDTH;
   d3dpp.BackBufferHeight = SCREEN_HEIGHT;

   // create a device class using this information and the info from the d3dpp stuct
   d3d->CreateDevice(D3DADAPTER_DEFAULT, D3DDEVTYPE_HAL, hWnd,
                     D3DCREATE_SOFTWARE_VERTEXPROCESSING, &d3dpp, &d3ddev);

   init_graphics();    // call the function to initialize the triangle }
```

... Direct3D ...


```
// this is the function used to render a single frame
void render_frame(void)
{
   d3ddev->Clear(0, NULL, D3DCLEAR_TARGET, D3DCOLOR_XRGB(0, 0, 0), 1.0f, 0);

   d3ddev->BeginScene();

      // select which vertex format we are using
      d3ddev->SetFVF(CUSTOMFVF);

      // select the vertex buffer to display
      d3ddev->SetStreamSource(0, v_buffer, 0, sizeof(CUSTOMVERTEX));

      // copy the vertex buffer to the back buffer
      d3ddev->DrawPrimitive(D3DPT_TRIANGLELIST, 0, 1);

   d3ddev->EndScene();

   d3ddev->Present(NULL, NULL, NULL, NULL);
}


// this is the function that cleans up Direct3D and COM
void cleanD3D(void)
{
   v_buffer->Release();    // close and release the vertex buffer
   d3ddev->Release();    // close and release the 3D device
   d3d->Release();    // close and release Direct3D
}
```

... Direct3D ...

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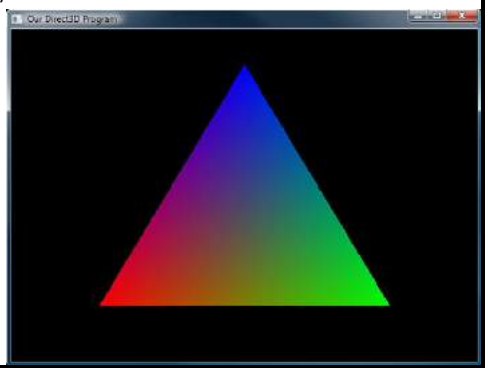
```
// this is the function that puts the 3D models into video RAM
   void init_graphics(void)
   {
      // create the vertices using the CUSTOMVERTEX struct
      CUSTOMVERTEX vertices[] =
      {
         { 400.0f, 62.5f, 0.5f, 1.0f, D3DCOLOR_XRGB(0, 0, 255), },
         { 650.0f, 500.0f, 0.5f, 1.0f, D3DCOLOR_XRGB(0, 255, 0), },
         { 150.0f, 500.0f, 0.5f, 1.0f, D3DCOLOR_XRGB(255, 0, 0), },
      };

      // create a vertex buffer interface called v_buffer
      d3ddev->CreateVertexBuffer(3*sizeof(CUSTOMVERTEX),
                                 0,
                                 CUSTOMFVF,
                                 D3DPOOL_MANAGED,
                                 &v_buffer,
                                 NULL);

      VOID* pVoid;    // a void pointer

      // lock v_buffer and load the vertices into it
      v_buffer->Lock(0, 0, (void**)&pVoid, 0);
      memcpy(pVoid, vertices, sizeof(vertices));
      v_buffer->Unlock();
   }
```



... Direct3D ...

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```
using System;
using System.Windows.Forms;
using Microsoft.DirectX;
using Microsoft.DirectX.Direct3D;


namespace MDX_Tutorial2
{
   class MainClass:Form
   {  private Device m_device = null;

      MainClass()
      {        this.Text = "Managed DirectX Tutorial 2";     }


      void InitGraphics()
      {  PresentParameters present_params = new PresentParameters();

         present_params.Windowed = true;
         present_params.SwapEffect = SwapEffect.Discard;

         m_device = new Device(0, DeviceType.Hardware, this,
                               CreateFlags.SoftwareVertexProcessing, present_params); }
```

Managed DirectX C# Graphics Tutorial 2: Drawing a Triangle
http:// http://gregs-blog.com

... Direct3D

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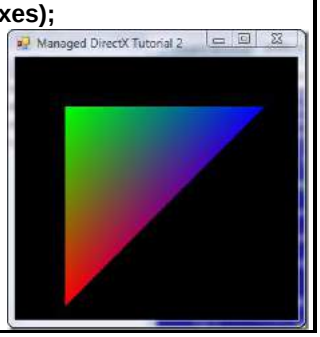
```
protected override void OnPaint(PaintEventArgs e)
{
  CustomVertex.TransformedColored[] vertexes = new CustomVertex.TransformedColored[3];

  vertexes[0].Position = new Vector4(50, 50, 0, 1.0f);
  vertexes[0].Color = System.Drawing.Color.FromArgb(0, 255, 0).ToArgb();
  vertexes[1].Position = new Vector4(250, 50, 0, 1.0f);
  vertexes[1].Color = System.Drawing.Color.FromArgb(0, 0, 255).ToArgb();
  vertexes[2].Position = new Vector4(50, 250, 0, 1.0f);
  vertexes[2].Color = System.Drawing.Color.FromArgb(255, 0, 0).ToArgb();

  m_device.Clear(ClearFlags.Target, System.Drawing.Color.FromArgb(0, 0, 0).ToArgb(), 1.0f, 0)
  m_device.BeginScene();
  m_device.VertexFormat = CustomVertex.TransformedColored.Format;
  m_device.DrawUserPrimitives(PrimitiveType.TriangleList, 1, vertexes);
  m_device.EndScene();
  m_device.Present();
}

static void Main()
{ MainClass MainForm = new MainClass();
  MainForm.InitGraphics();
  Application.Run(MainForm);   } } }:
```



Modeli, prostori i transformacije

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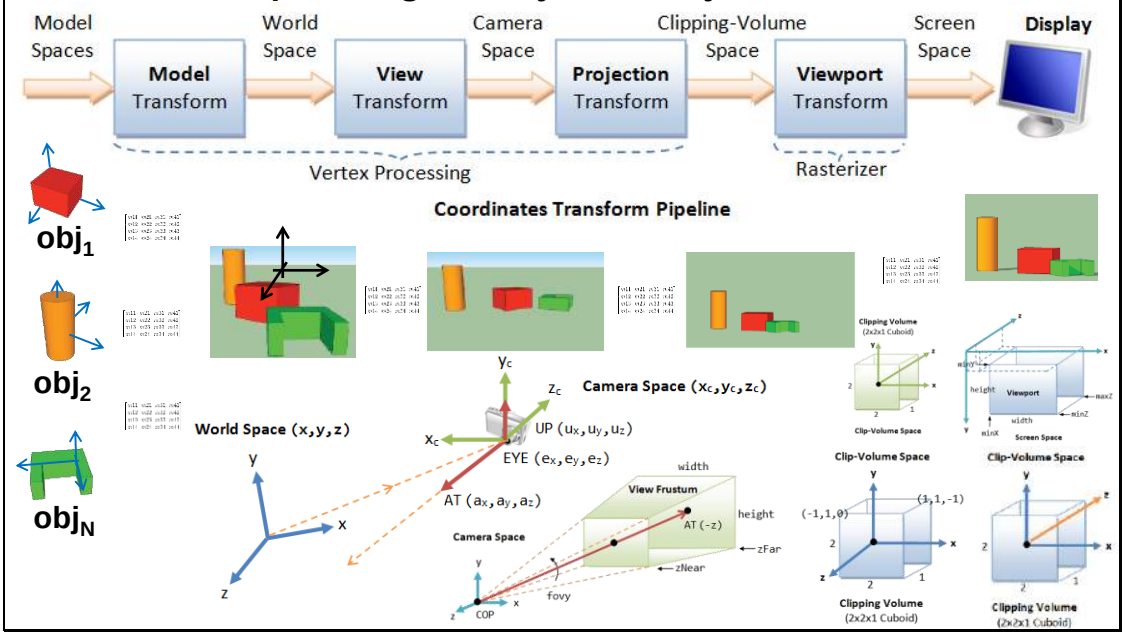
Kako načiniti 3D objekte/modele, pa ih staviti na 3D scenu, šetati se scenom i na 2D prikazu gledati njen sadržaj?



Modeli - 3D primitive

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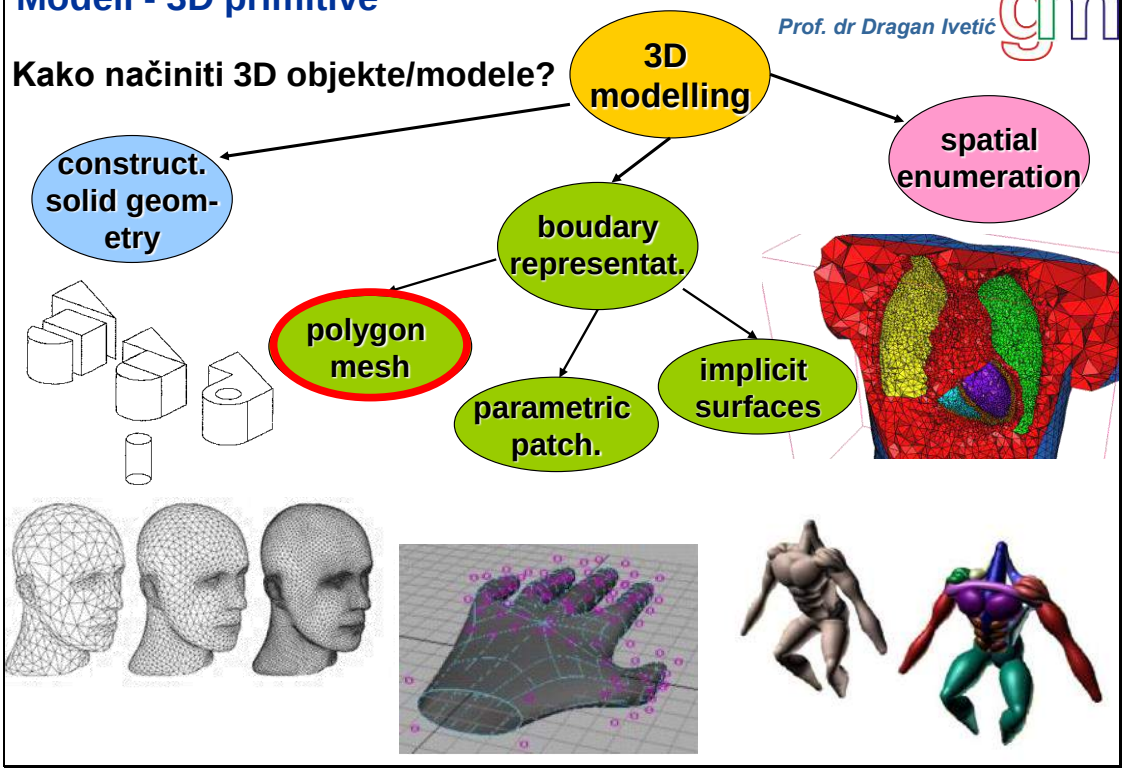
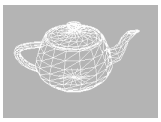
Kako načiniti 3D objekte/modele?



Modeli



Mreža poligona ...

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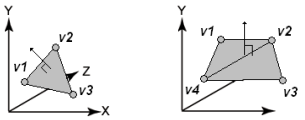
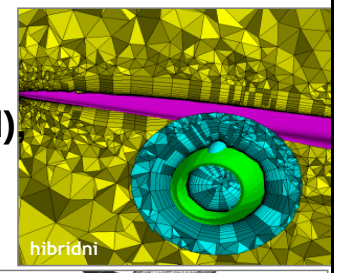
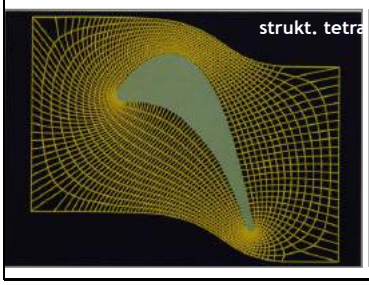
Skup ivica, temena i poligona spojenih tako da:

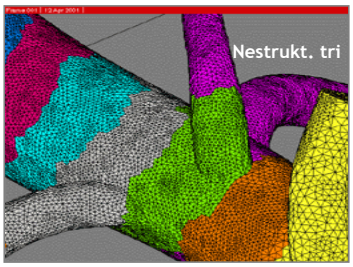
- **svaka ivica je deljena među najviše dva susedna poligona,**
- **ivica povezuje dva temena,**
- **poligon je zatvorena sekvenca ivica.**

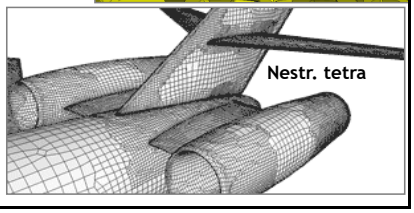


- **ogroman broj algoritama**
  - **zavisno od oblika poligona (tri, tetra),**
  - **a i same mreže (nestrukt., strukt. – grid),**

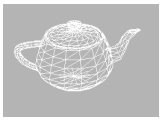








Modeli



... Mreža poligona ...

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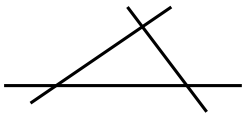
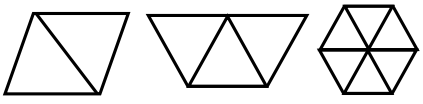
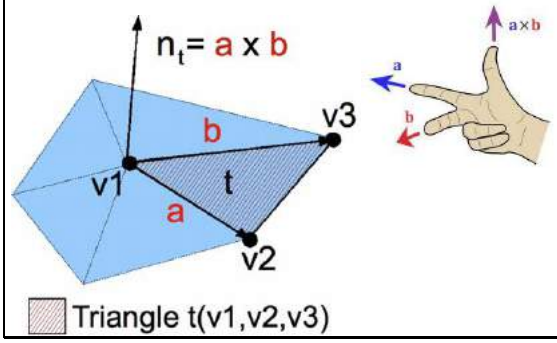
Načiniti "kožu" objekta, iznutra su šuplji.



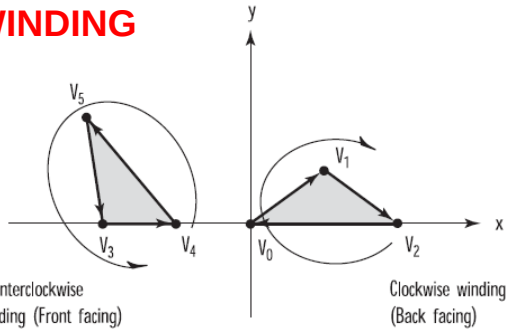
Da li koristiti trougao ili tetraedar?

- **matematički jednostavno (3 tačke i 3 ivice),**
- **uvek planaran i nikad konkavan,**
- **gradivan za ostale oblike,**
- **ima prednju i zadnju stranu,**
  - **$v_1v_2v_3$ == $v_3v_2v_1$??**

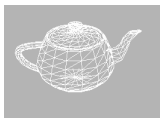




WINDING



Modeli



... Mreža poligona ...

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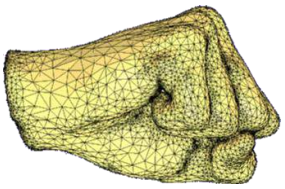
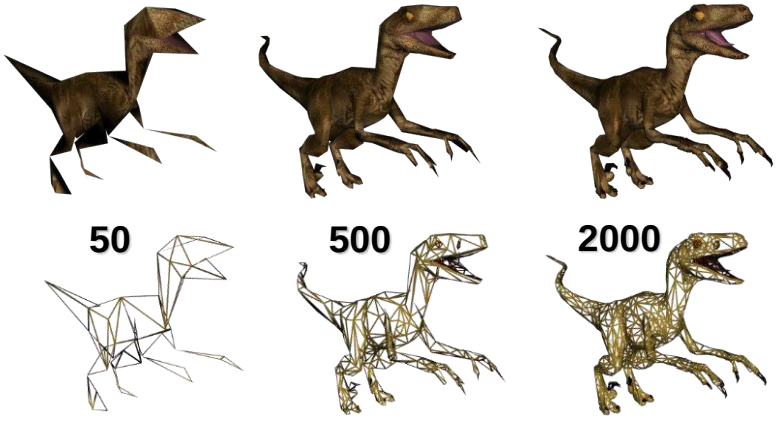
Veća nepravilnost površine modela zahteva ? broj trouglova,

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

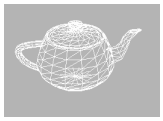




NE!

LOD zavisi od ...

Modeli



... Mreža poligona ...

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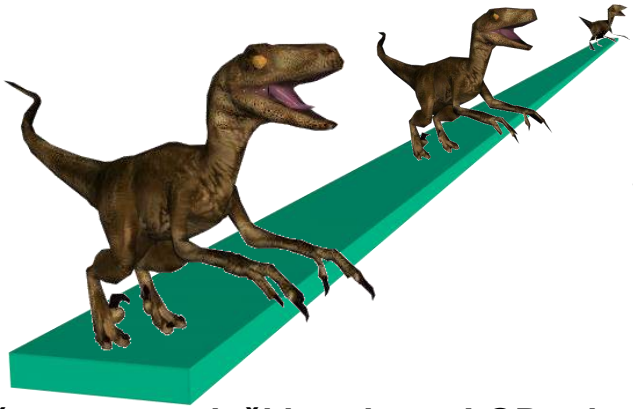
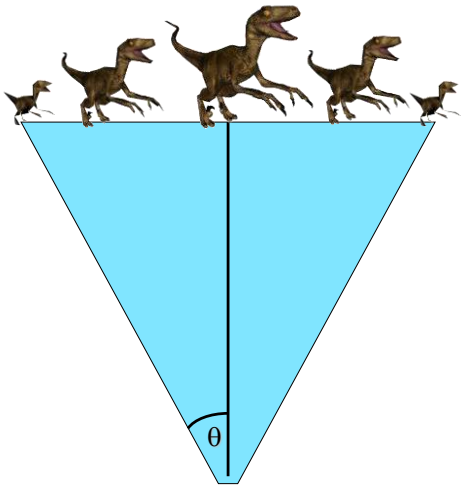
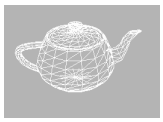
LOD opada sa rastojanjem gledaoc-objekat!





što opet povlači i zavisnot LOD od
ugla gledanja na objekat,
brzine objekta,
konteksta scene, ... ,
rezolucije projekcione površine!

Modeli



... Mreža poligona ...

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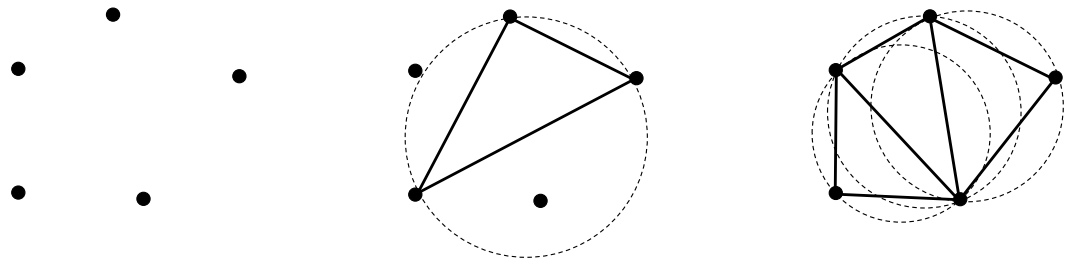
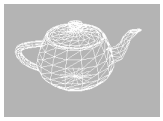
Kako da napravim 3D model objekta pomoću poligona sa odabranim LOD?

1. Generiše se skup tačaka koji pripadaju površini objekta:
- **ručno,**
- **matematikom, ili**
- **skeniranjem.**

2. Primeni se Delaunay-ova triangulacija.



Modeli



... Mreža poligona ... matematikom ...

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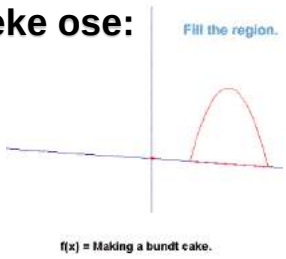
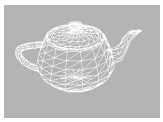
1. Tela koja se dobijaju vrtnjom krive oko neke ose:
- **sfera,**
- **cilindar,**
- **torus,**
- **konus...**



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

Modeli



... Mreža poligona ...

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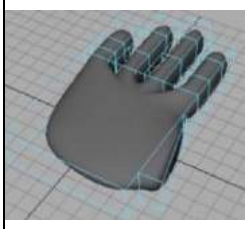
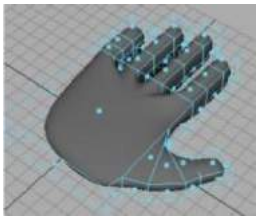
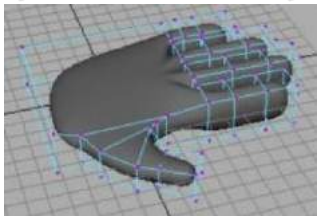
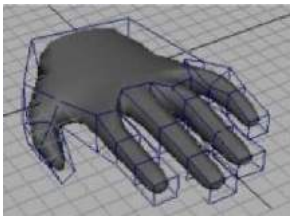
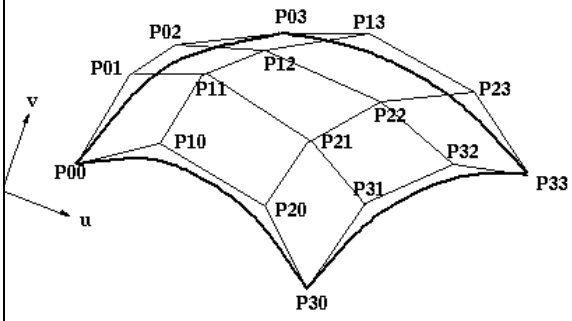
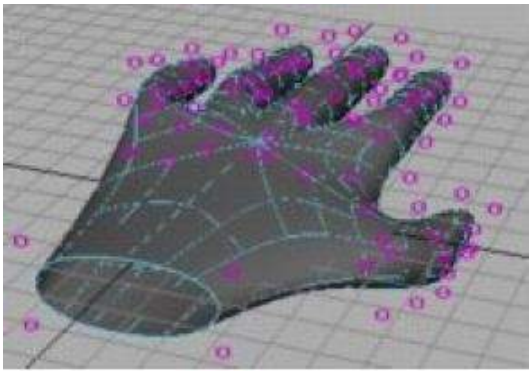
... matematikom

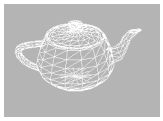
3. Non-Uniform Rational B-splines krivama/površinama





Modeli



... Mreža poligona ...

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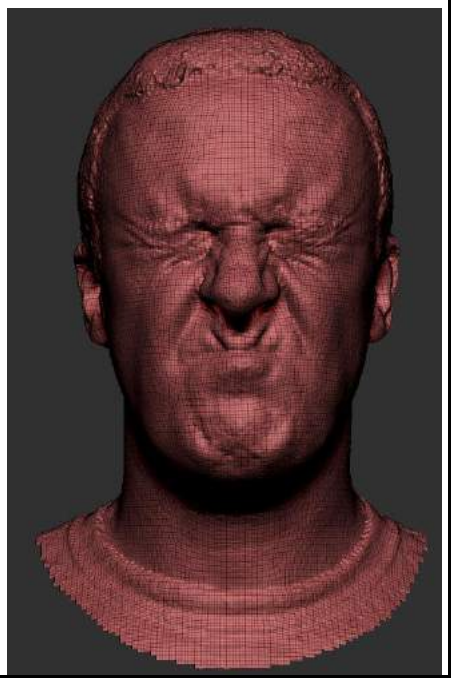
skeniranjem...

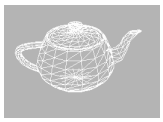
1. 3D face capture - 18 kamera svaka sa 4.096x4.096 piksela u 1/10.000 s,







Modeli



... Mreža poligona ... ... skeniranjem

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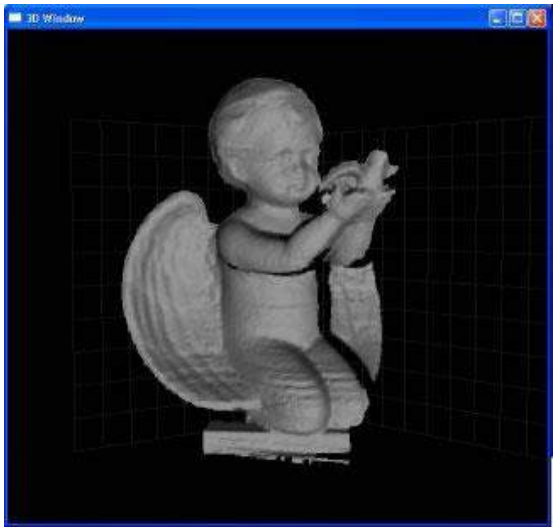
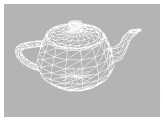
2. lasersko 3D skeniranje,
DAVID-Laserscanner 2.6.1 - Portable,



Modeli



... Mreža poligona ...

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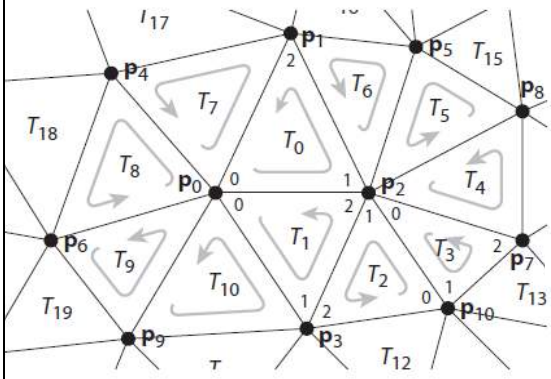
Kako definisati trouglove mreže na (skladišno i procesno) efikasan način?

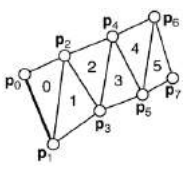
verts | (x_0,y_0,z_0) | (x_1,y_1,z_1) | (x_2,y_2,z_2) | (x_3,y_3,z_3) | …

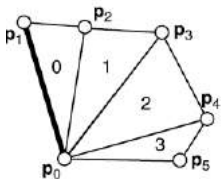


tInd | (0,2,1) | (0,3,2) | (10,2,3) | (2,10,7) | …

tStrips | (4,0,1,2,5,8) | (6,9,0,3,2,10,7) | …

tFan | (0,2,1,4,6,9,3,2) | (5,1,2,8,…) | …

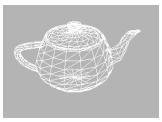




Osnovne definicije trouglova:

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

Modeli



... Mreža poligona

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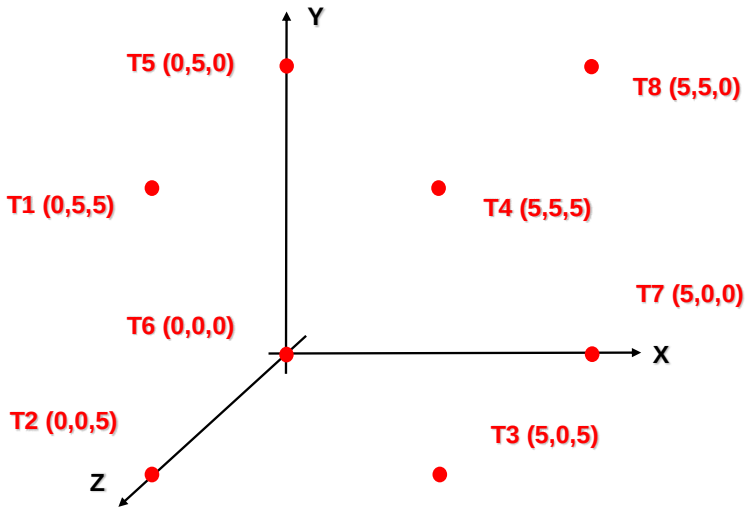
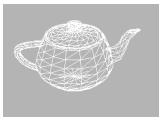
Predstaviti temena pomoću liste, ventilatora i trake.



Modeli



... Mreža poligona

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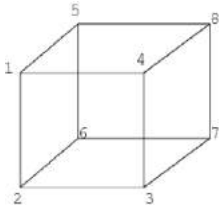
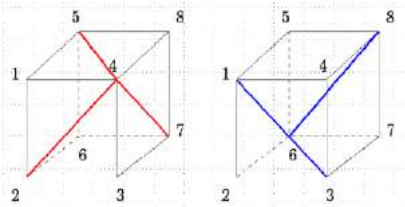
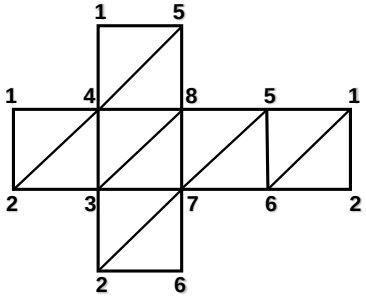


trouglovi:
T241, T234, T384, T378, T758, T765, T615, T625, T451, T485, T273 i T267.



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

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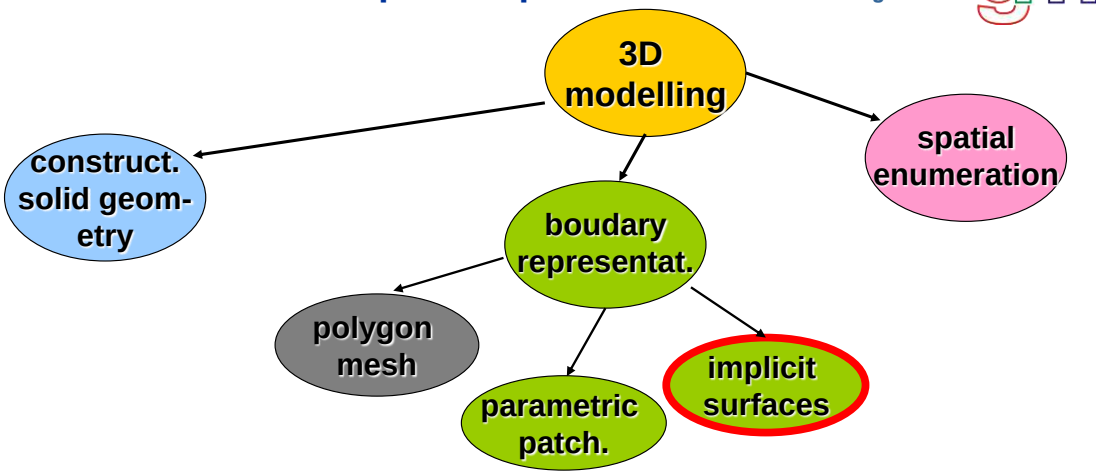
Implicitne površine ...



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

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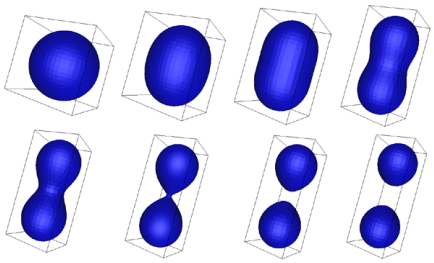
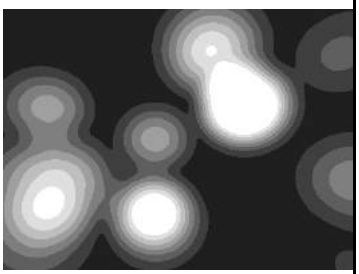
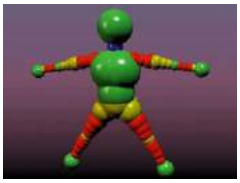
... Implicitne površine ...



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

$$\sum_{i=1}^{N} metaballs_i\,(x, y, z) \le PRAG$$





Modeli

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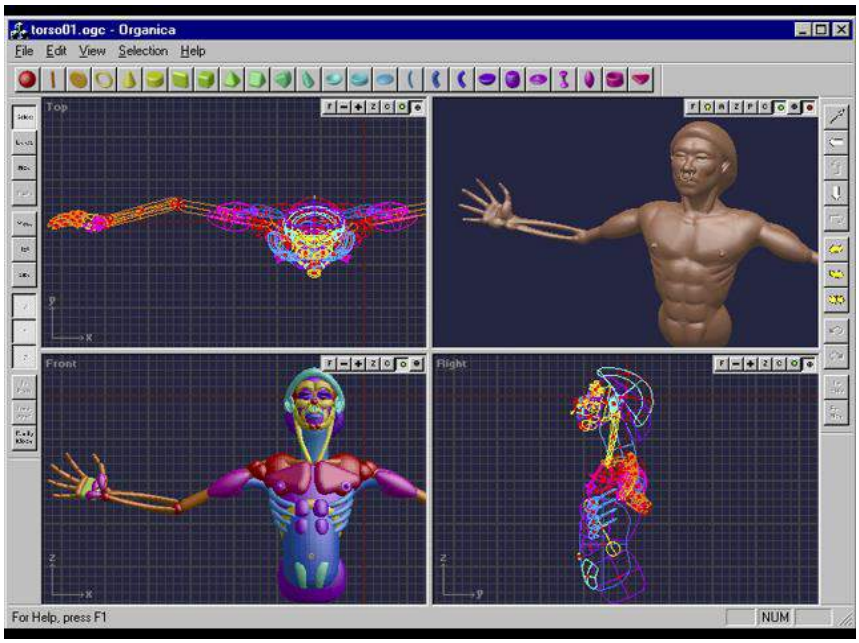
... Implicitne površine ...

Programsko okruženje Organica



Modeli

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... Implicitne površine

Modeli

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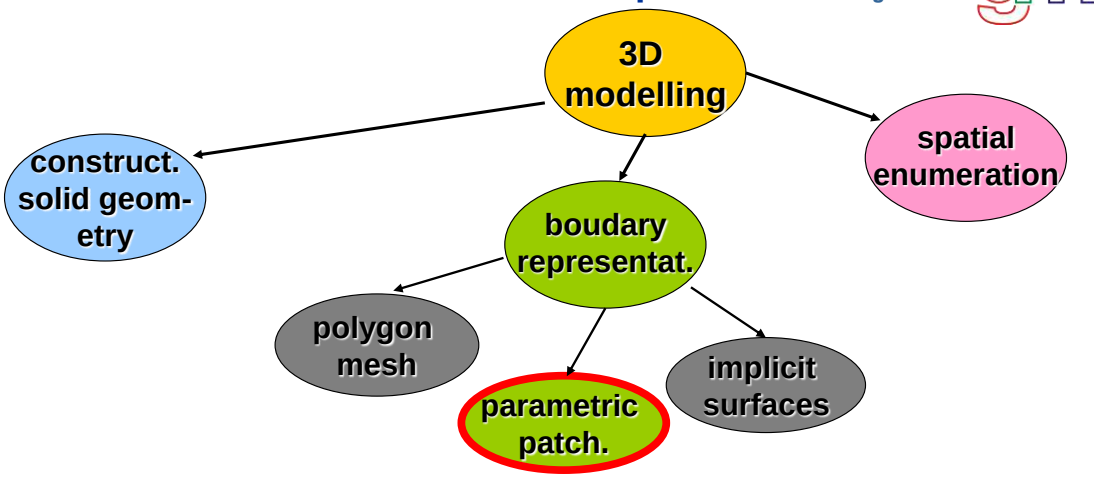
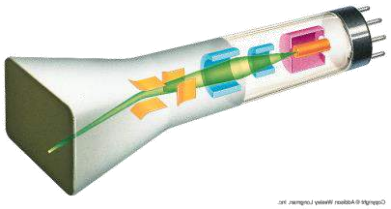
Parametarske zakrpe ...



Da li crtati 2D krivu eksplicitno

$$y = A\,x^3 + B\,x^2 + C\,x + D$$

i to krivu u obliku petlje?



Modeli

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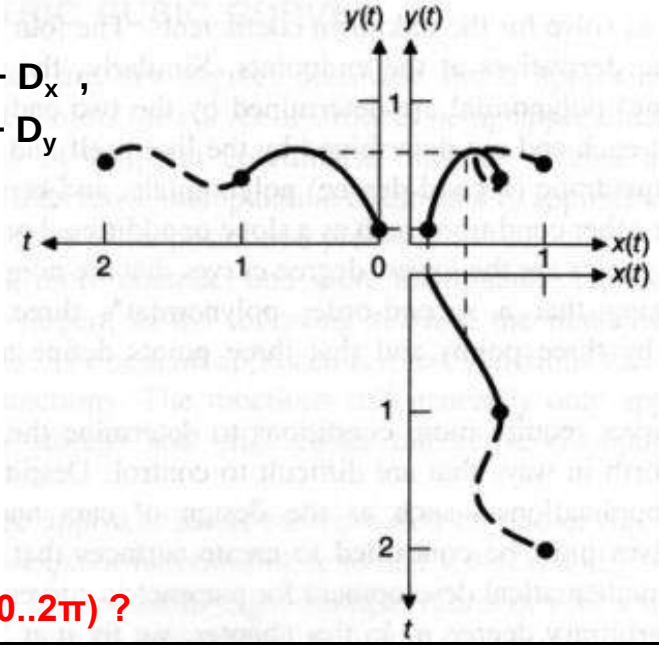
… Parametarske zakrpe ...

Jednostavnije parametarskom predstavom krive

$$x(t) = A_x\,t^3 + B_x\,t^2 + C_x\,t + D_x\ ,$$
$$y(t) = A_y\,t^3 + B_y\,t^2 + C_y\,t + D_y$$



Šta će se prikazati za

(x,y) = (cos t, sin t) , t ϵ (0..2π) ?

Modeli

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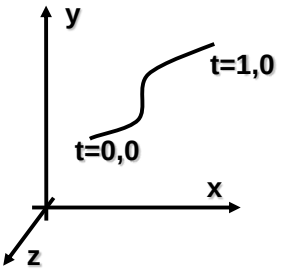
... Parametarske zakrpe ...

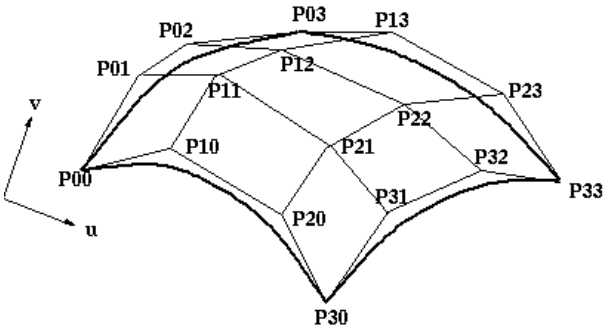
Šta bi bilo formirano sa

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



Šta bi bilo formirano sa

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



Modeli

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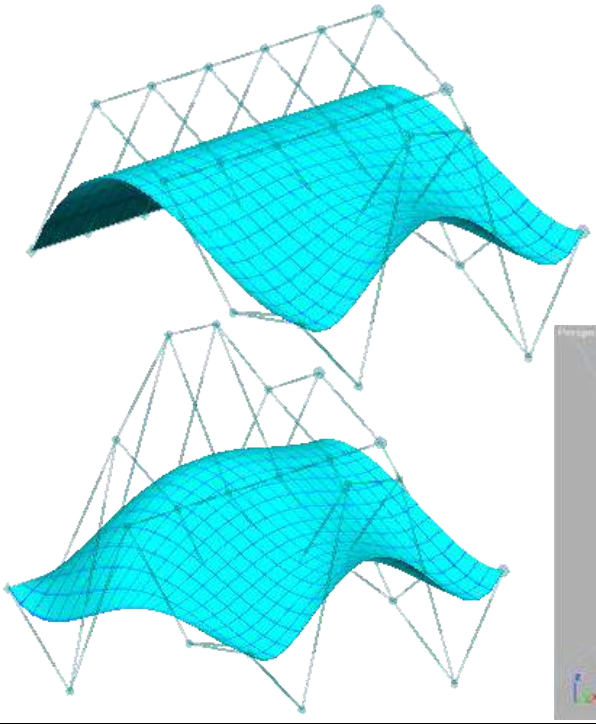
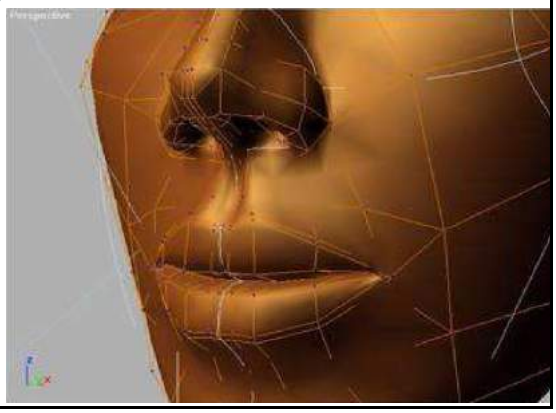
... Parametarske zakrpe





Modeli

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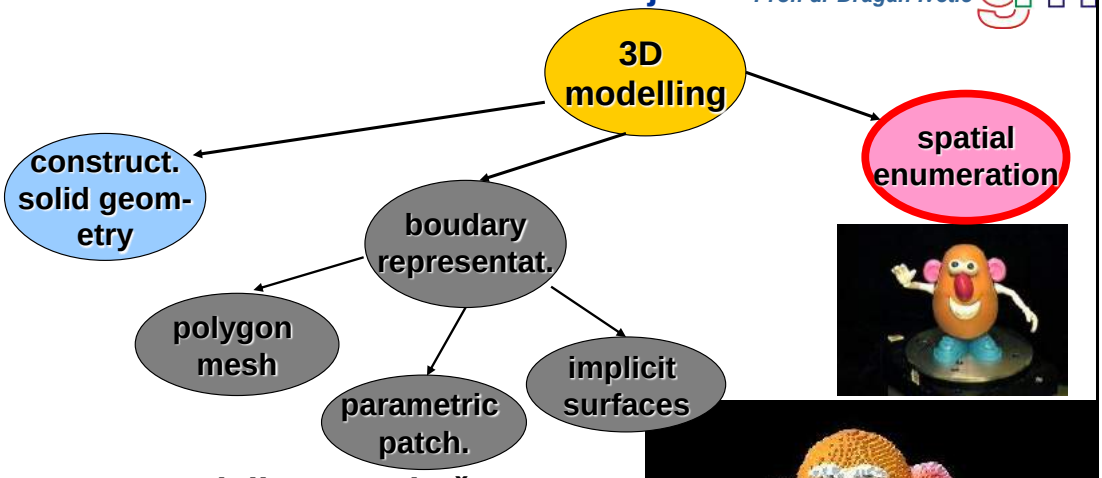
Prostorna enumeracija ...



- prostor se deli na manje čvrste (pune) delove koji tako formiraju 3D objekat,
- obično su to kocke čija veličina diktira i finoću modela.

Modeli

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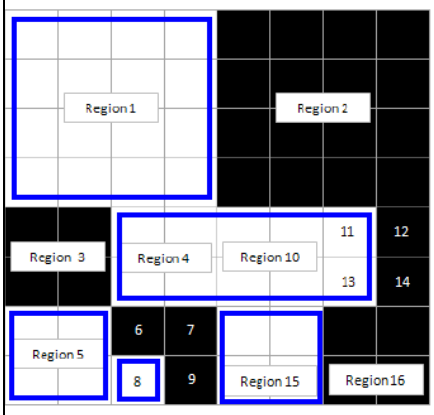
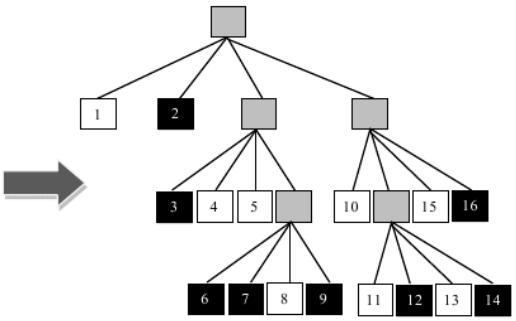
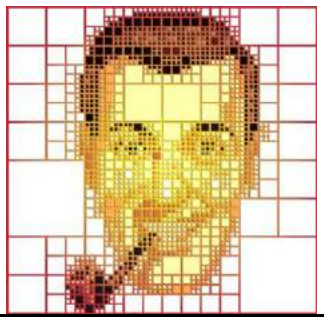
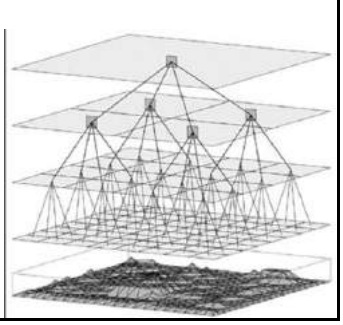
... Prostorna enumeracija ...

- za 2D - QUADTREE,









Modeli

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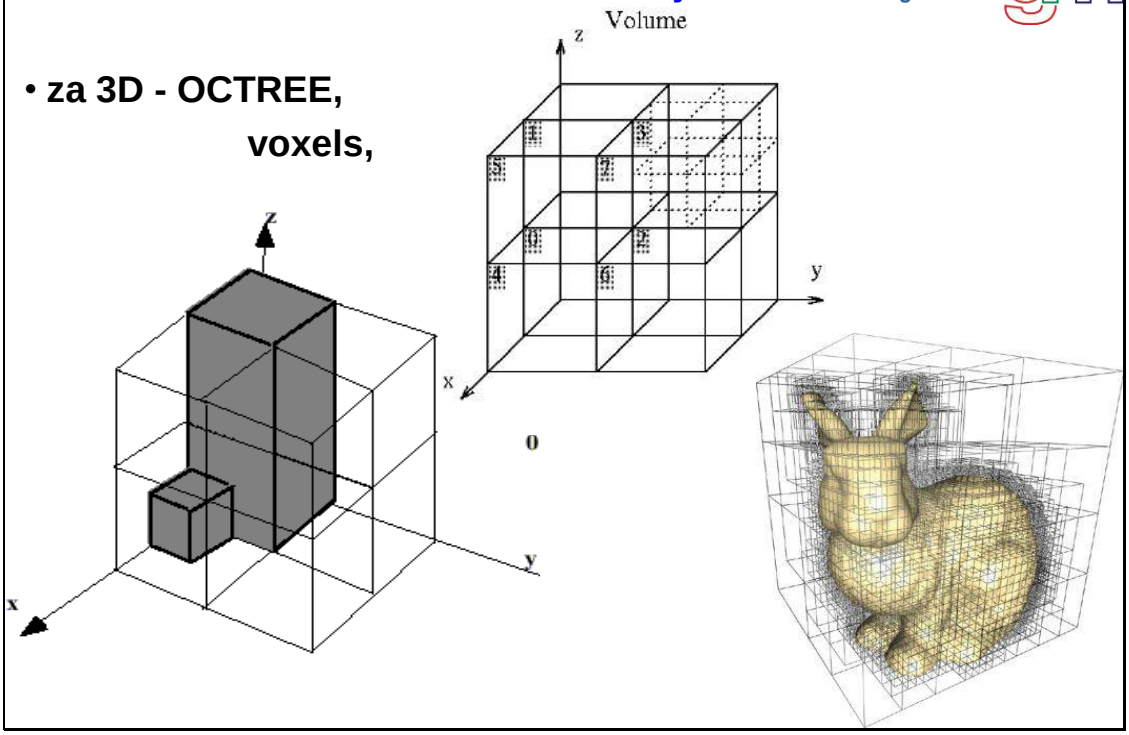
... Prostorna enumeracija

- za 3D - OCTREE,
  voxels,



Modeli

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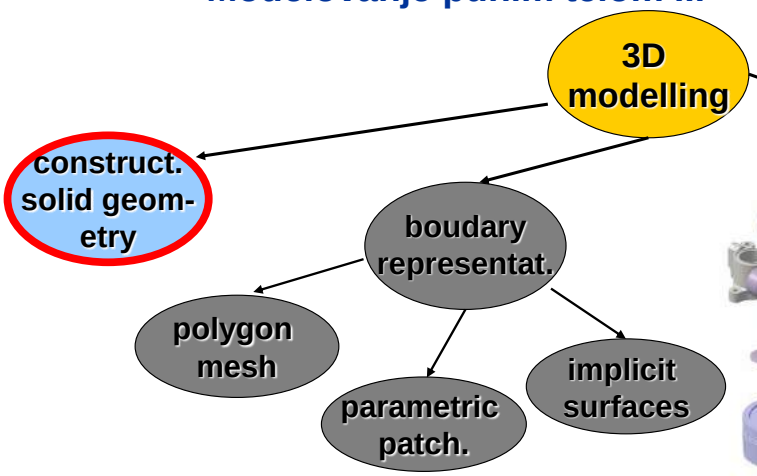
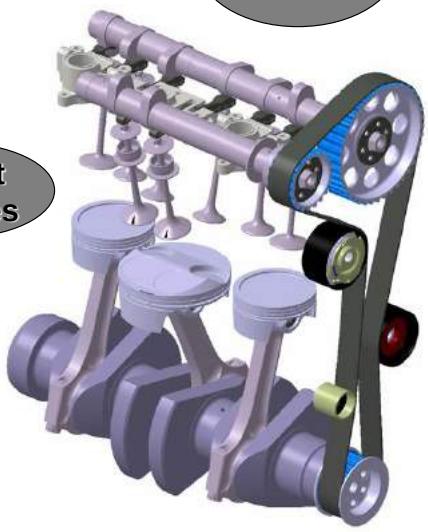
Modelovanje punim telom ...



- solid modeling - kreirali za CAD,



Modeli

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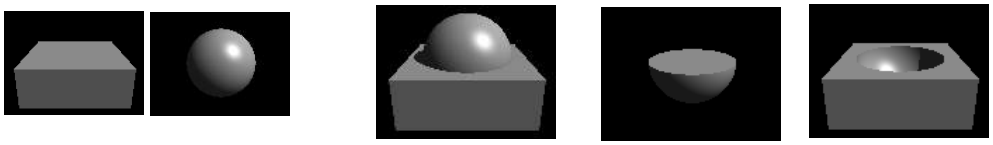
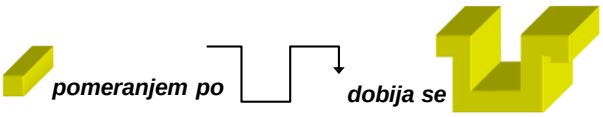
... Modelovanje punim telom ...

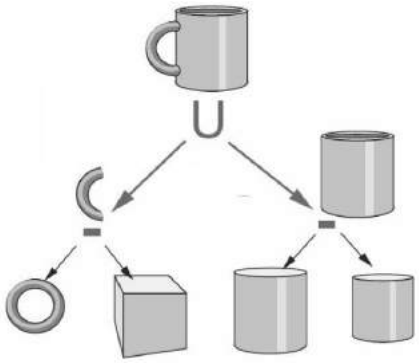
- **solid modeling - kreirali za CAD,**
- **operacija skupova (U , ∩ , /)**



nad primitivama (geometrijska tela),

- **sweep.**





Modeli

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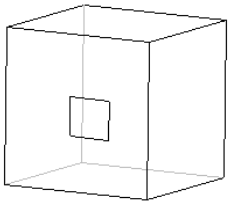
... Modelovanje punim telom ...

- **posle su dodali nove fukcije 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, rebra i sl.

Modeli

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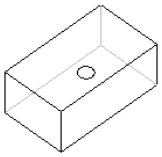
... Modelovanje punim telom

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

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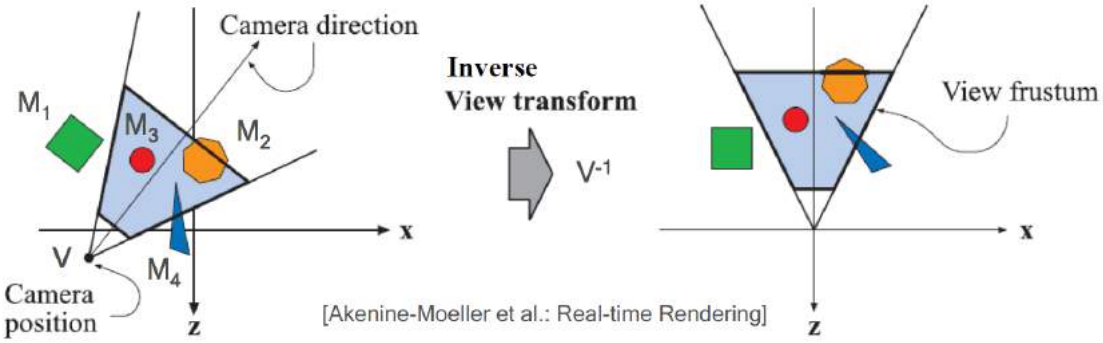
Zašto ...

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



- **M_i i V su 4 x 4 matrice 3D transformacije,**
- **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
Elementarne transformacije ...

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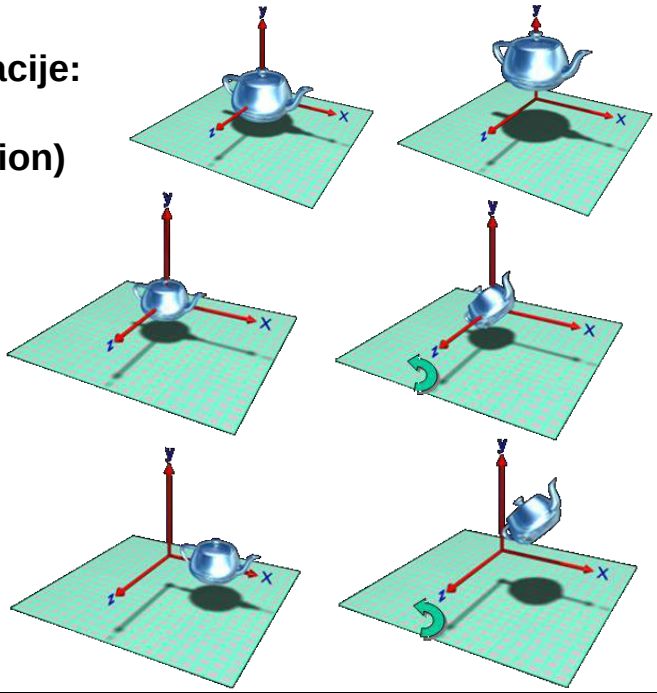
Elementarne transformacije:

TRANSLACIJA (translation)



ROTACIJA (rotation)

3D transformacije
... Zašto

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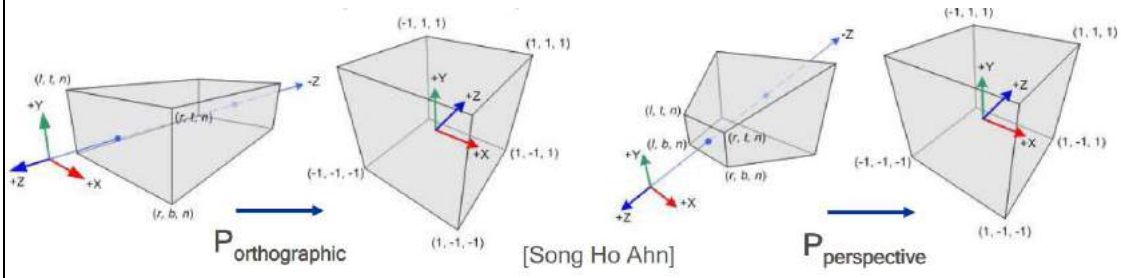
- **da ortografski ili perspektivno projektujemo 3D geometriju na ravan,**



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

3D transformacije
... Elementarne transformacije

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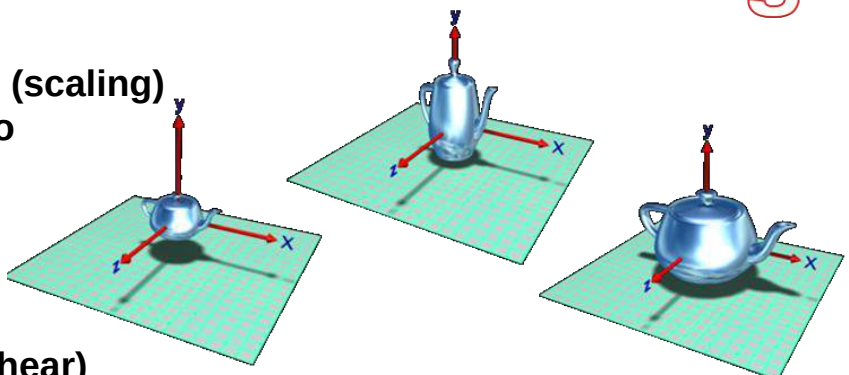
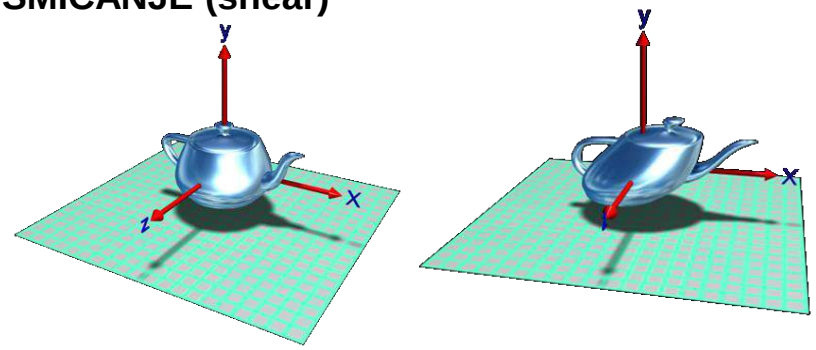
SKALIRANJE (scaling)
(ne)uniformno



SMICANJE (shear)



3D transformacije
Afina transformacije

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Afina transformacija (affine transfotmation)
- **održava kolinearnost**
  - **tačke na liniji se transformišu u tačke na liniji,**
- **održava proporciju**
  - **odnosi razdaljina među tačkama ostaju isti,**
- **održava paralelizam**
  - **paralelne linije ostaju paralelne i posle transformacije,**
- **uglovi i dužine se ne održavaju,**

- **translacija, rotacija, skaliranje, smicanje i refleksija su afine transformacije,**
- **ortografska projekcija jeste kombinacija afine transform.,**
- **perspektivna transformacija nije afine.**

3D transformacije

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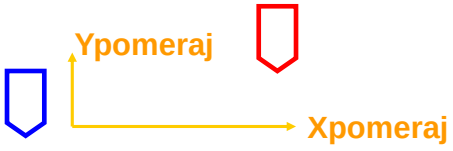
Primeri u 2D ...

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 , Sx=Sy
- **Sx,Sy>1, veće i dalje od (0,0),**
- **Sx,Sy<1, manje i bliže**

Neuniformno, Sx≠Sy
- **Sx,Sy>1, veće i dalje od (0,0),**
- **Sx,Sy<1, manje i bliže**

Za
Sx=0,25
Sy=0,5

3D transformacije

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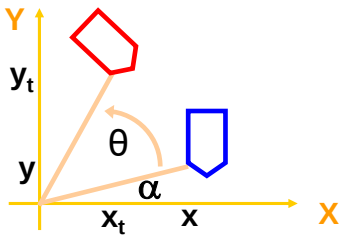
... Primeri u 2D ...

2D ROTACIJA



x = r cos(α)
y = r sin (α)

x_t = r cos(α+θ) = r cos(α) cos(θ) - r sin(α) sin(θ) = x cos(θ) - y sin(θ)
y_t = r sin (α+θ) = r cos(α) sin(θ) + r sin(α) cos(θ) = x sin(θ) + y cos(θ)

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

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

3D transformacije

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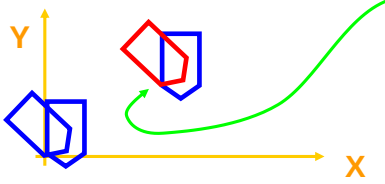
... Primeri u 2D

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



Translacija za (-x, -y) u koord. početak
Rotacija za ugao α
Translacija za (x, y) u početni položaj

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

Dosta nesretno rešenje u pogledu efikasnosti!

Zašto?

Kome i kako pomoći da se dobije na efikasnosti?

3D transformacije

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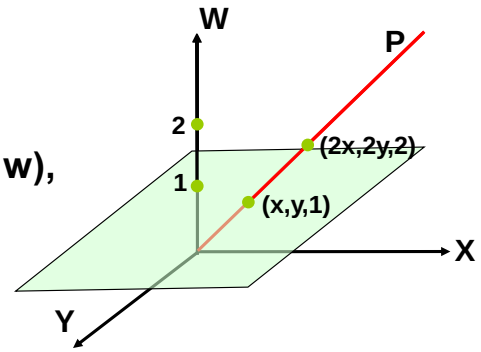
Homogenizacija

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 ≥ 1 !!**
- **u RG je w = 1 za tačku,**



(x,y,1) ≡ (2x,2y,2) ≡ (3x,3y,3) ≡ ... ≡ (*n* x,*n* y,n)

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

Za w → 0, x i y koordinate → ∞.
Koordianata (x,y,0) je tačka u beskonačnosti,
u RG se naziva vektorom u pravcu (x,y).

3D transformacije

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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

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... Homog. 2D trans.

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

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Homog. 3D trans. ...

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

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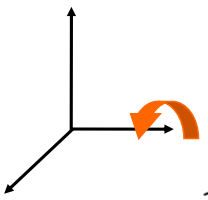
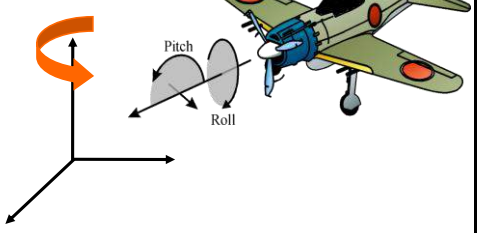
... Homog. 3D trans. ...

3D ROTACIJA po svakoj od osa

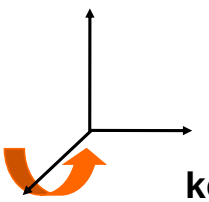
$$\begin{bmatrix} x_t \\ y_t \\ z_t \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) & 0 \\ 0 & \sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$



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



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



komutativnost?

3D transformacije

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... Homog. 3D trans.

Doprinos homogenih koordinata - homogenizacija matrice transformacija

$$\begin{bmatrix} m_{00} & m_{01} & m_{02} & t_0 \\ m_{10} & m_{11} & m_{12} & t_2 \\ m_{20} & m_{21} & m_{22} & t_3 \\ p_0 & p_1 & p_2 & w \end{bmatrix}$$

pri čemu su
m_{ii}
t_i
p_i
w

3D transformacije

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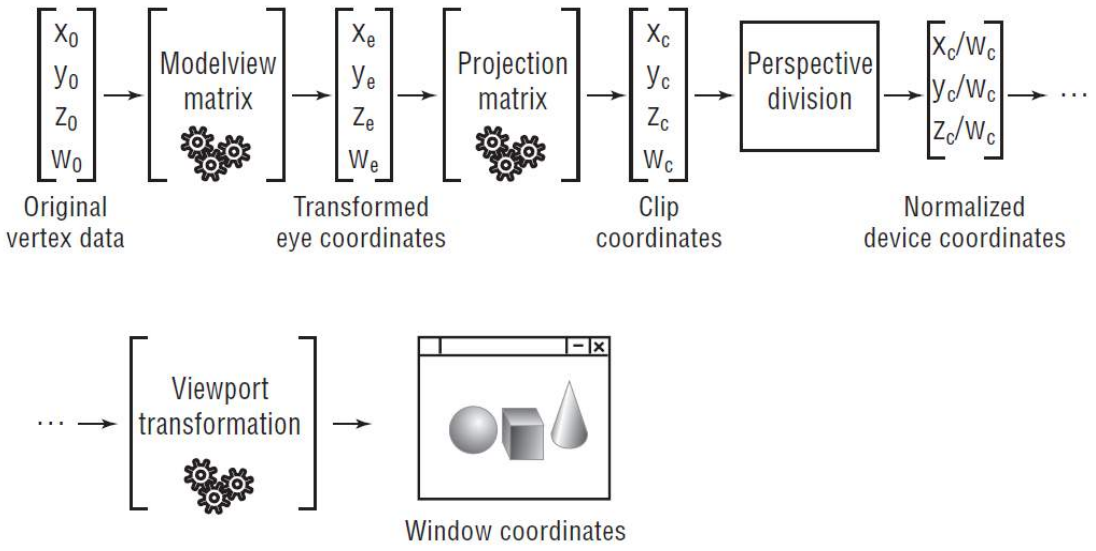
Pajplajn transformacija temena



3D transformacije
Transformacija prozora …

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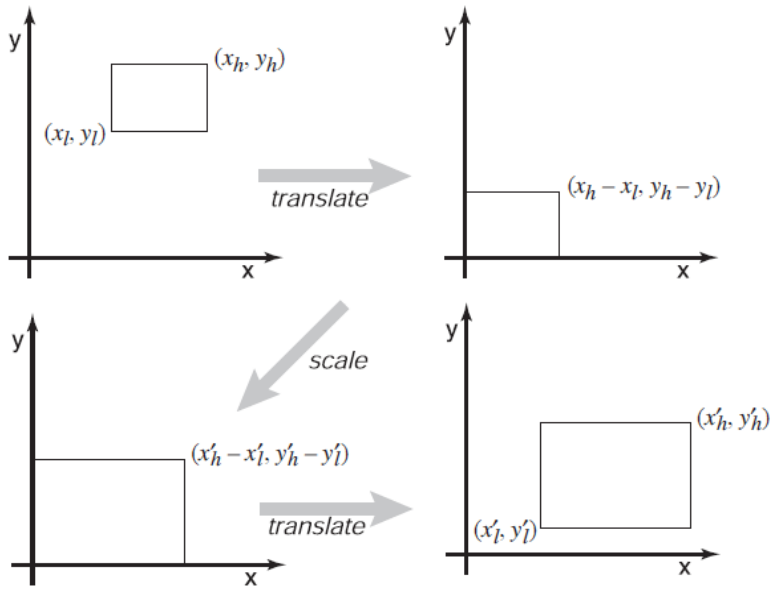
Kreirati matricu koja bi tačke iz jednog pravougaonika $[x_l,x_h]x[y_l,y_h]$ u drugi pravougaonik $[x`_l,x`_h]x[y`_l,y`_h]$!



3D transformacije
… Transformacija prozora …

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

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

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

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

3D transformacije
… Transformacija prozora

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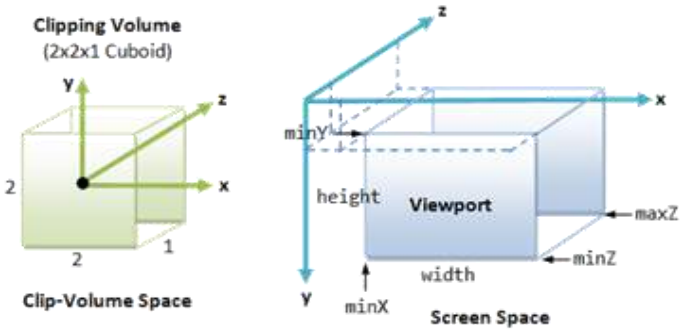
Kreirana matrica je Viewport transformacija!



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

3D transformacije
Transformacija prostora …

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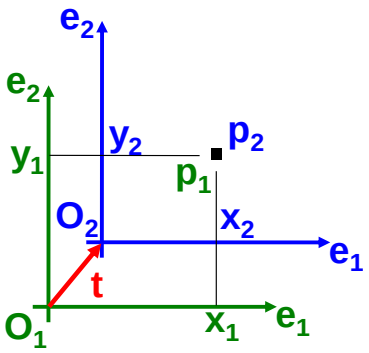
Kako animirati vožnju Homera kroz Springfild?

3D transformacije
... Transformacije prostora ...

Translacija koordinatnog sistema

$C_1 = (O_1, \{e_1,e_2,e_3\})$, u

$C_2 = (O_2, \{e_1,e_2,e_3\})$



$p_2 = p_1 - t$, odnosno $p_2 = T(-t)\ p_1$

translacija koord. početka za t odgovara translaciji objekata za -t

3D transformacije
... Transformacije prostora ...

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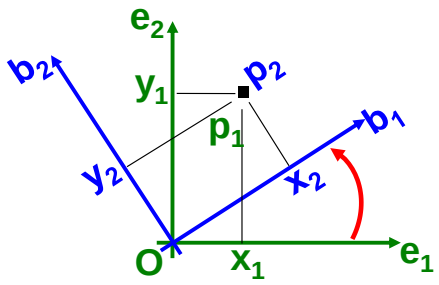
Rotacija koordinatnog sistema

$C_1 = (O, \{e_1,e_2,e_3\})$, u

$C_2 = (O, \{b_1,b_2,b_3\})$



$p_2 = R(-\theta)\ p_1$

3D transformacije
... Transformacije prostora ...

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Kako renderovati unutrašnjost auta dok Homer vozi napred, odnosno kada skreće?

Kako prikazivati ulice i zgrade Springfilda na vetrobranskom staklu dok Homer vozi napred, odnosno kada skreće?

Kako prikazivati scenu vožnje iz treće kamere?

3D transformacije
... Transformacije prostora ...

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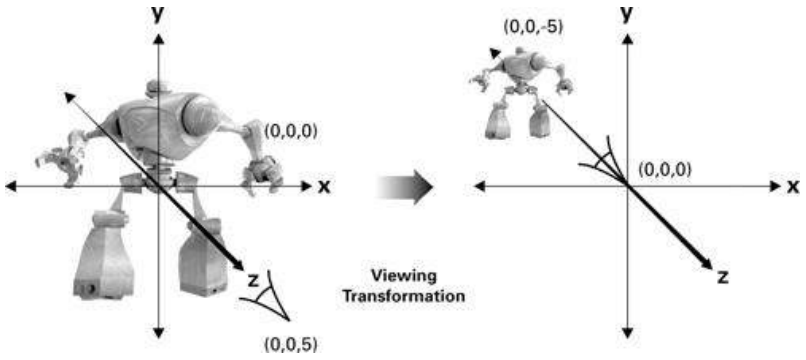
Primena transformacija koordinatnih sistema

view transform - WS → VS

$(O_1, \{e_1,e_2,e_3\}) \rightarrow (O_2, \{b_1,b_2,b_3\})$

kompozicija T_{kamera} i R_{kamera} u komp.$_{svaki\ objekat}$ T^{-1}_{kamera} i R^{-1}_{kamera}



3D transformacije

Transformacije prostora

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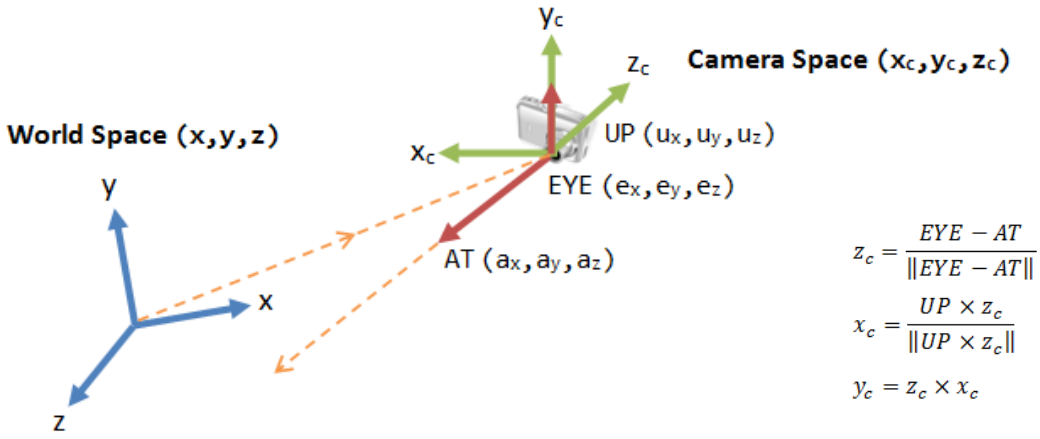
Apstrakcija kamere za ModelView transformaciju



$$z_c = \frac{EYE - AT}{\|EYE - AT\|}$$

$$x_c = \frac{UP \times z_c}{\|UP \times z_c\|}$$

$$y_c = z_c \times x_c$$

View Matrix: $\boldsymbol{M_{view}} = \boldsymbol{R}\,\boldsymbol{T} = \begin{bmatrix} x_x^c & x_y^c & x_z^c & 0 \\ y_x^c & y_y^c & y_z^c & 0 \\ z_x^c & z_y^c & z_z^c & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & -e_x \\ 0 & 1 & 0 & -e_y \\ 0 & 0 & 1 & -e_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} x_x^c & x_y^c & x_z^c & -e_x \cdot x_c \\ y_x^c & y_y^c & y_z^c & -e_y \cdot y_c \\ z_x^c & z_y^c & z_z^c & -e_z \cdot z_c \\ 0 & 0 & 0 & 1 \end{bmatrix}$

Kako deo 3D prostora prikazati na 2D?

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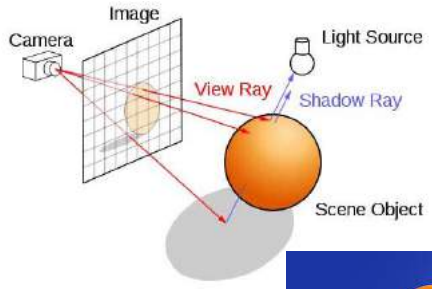
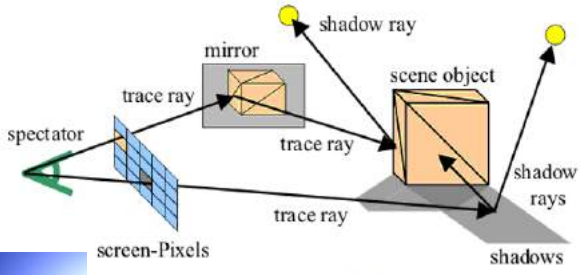
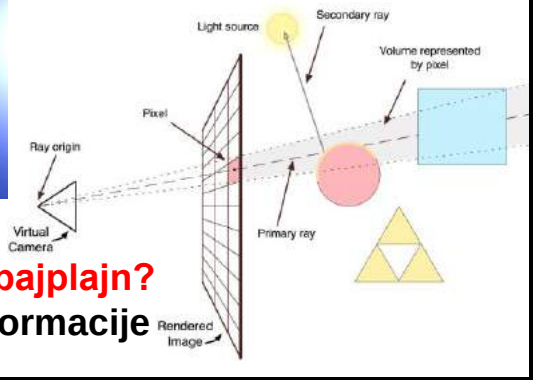
Moguće su dve strategije:

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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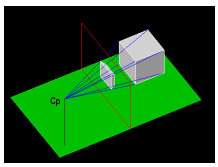
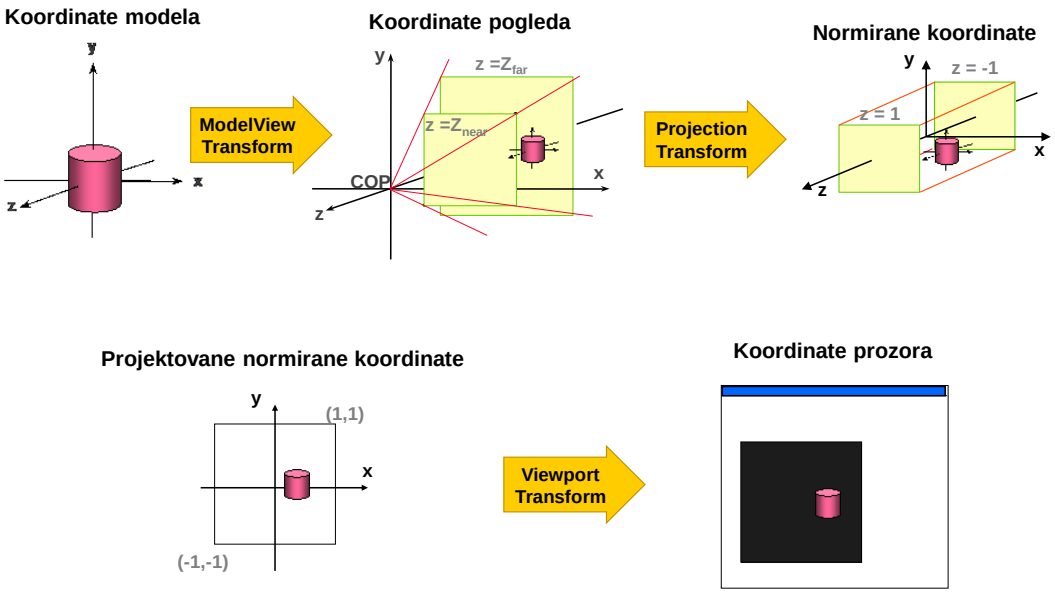


projection pipeline,



KLASE PROJEKCIJA

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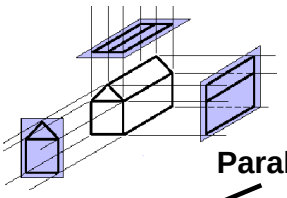
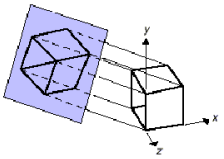


Planarna projekcija

Paralelna

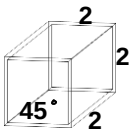
Ortogonalna

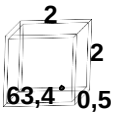
- gore/dole - na y,
- napred/nazad - z,
- leva/desna - x,
- izometrijska (na ravan pod istim uglom na x-y-z-ose, [2,-2,-2]).



Kosa

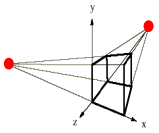
- kavaljerska (fina), smer projekcije zatvara 45˚ na proj. ravan
- kabinetska, zatvara 63,4˚, realnija projekcija.

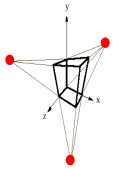




Perspektivna

- iz jedne tačke - COP,
- iz dve tačke (dodatno okreće projektovanu sliku u ravni),
- iz tri tačke (retko, dodatno okreće objekat),





PROJEKCIJA POGLEDA

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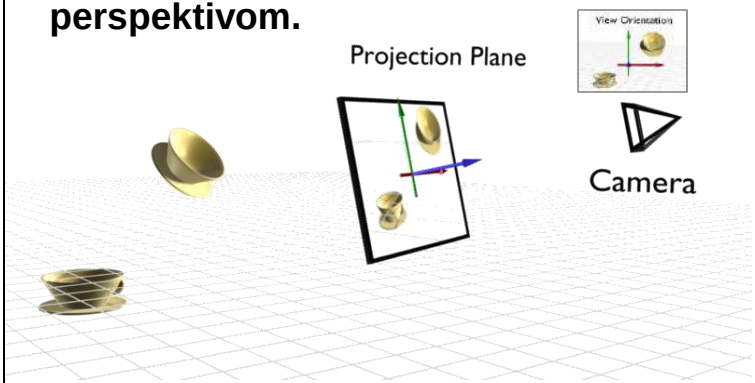
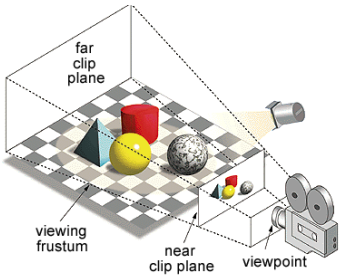
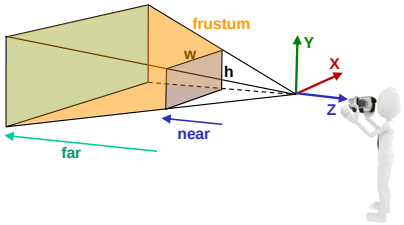
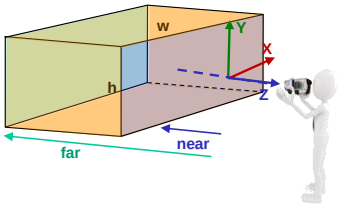
- **želimo generisati 2D sliku 3D scene iz ugla kamere,**
- **moramo projektovati objekte scene paralelno ili perspektivom.**









ORTOGONALNA PROJEKCIJA
na projekcionu ravan

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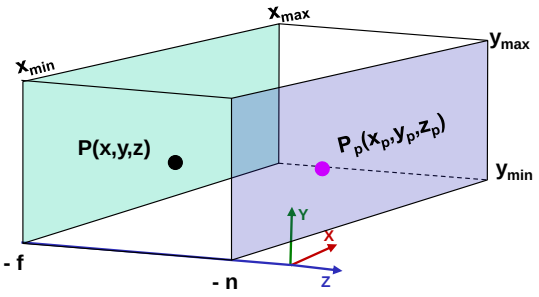


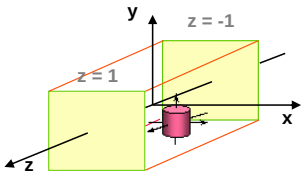
- **bilo koju tačku P(x,y,z) projektovati na front (-n),**
- **odrediti koordinate P_p**

  x_p, y_p , z_p

- **uvedemo projekcionu ravan d: 0 .. –f,**
- **Kako na kraju svesti kuboid na normiranu kocku?**

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

Normirane koordinate



ORTOGONALNA PROJEKCIJA
na normiranu kocku ...

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- **OpenGL,** $\left[x_p, y_p, z_p, 1\right]^T = M_{OrtoNorm}\left[x, y, z, 1\right]^T$

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

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

ORTOGONALNA PROJEKCIJA
na normiranu kocku ...

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

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

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

PROJEKCIJA U PERSPEKTIVI
na projekcionu ravan d

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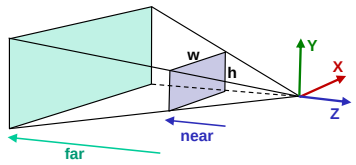

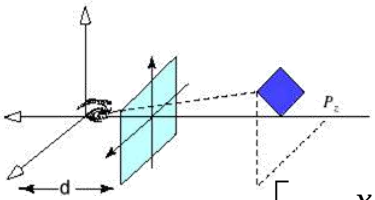

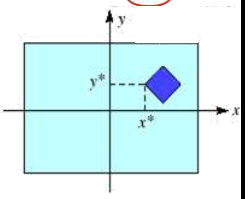

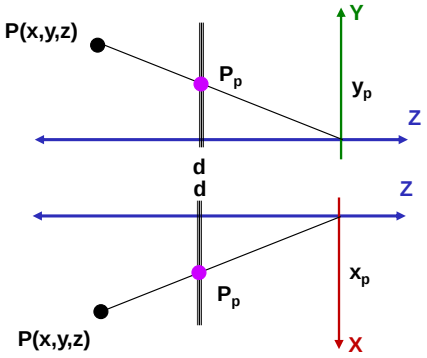

$$\begin{bmatrix} x_P \\ y_P \\ -d \\ 1 \end{bmatrix} = \begin{bmatrix} -d\frac{x}{z} \\ -d\frac{y}{z} \\ -d \\ 1 \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ -\frac{z}{d} \end{bmatrix}$$

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

x_p = ?
y_p = ?

$$\frac{x_P}{d} = \frac{x}{-z}, \quad \frac{y_P}{d} = \frac{y}{-z}$$

PROJEKCIJA U PERSPEKTIVI
OpenGL matrica projekcije ...

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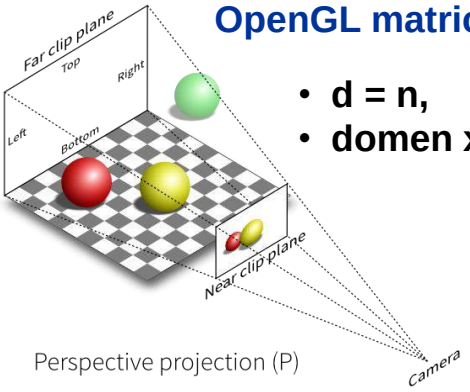

Perspective projection (P)

- **d = n,**
- **domen x_p vrednosti** $l \le x_P \le r$

$$0 \le x_P - l \le r - l$$

$$0 \le \frac{x_P - l}{r - l} \le 1 \xrightarrow{*2} 0 \le 2\frac{x_P - l}{r - l} \le 2$$

$$\xrightarrow{-1} -1 \le 2\frac{x_P - l}{r - l} - 1 \le 1 \longrightarrow -1 \le \frac{2x_P - 2l - r + l}{r - l} \le 1$$

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

- **domen y_p vrednosti** $b \le y_P \le t \longrightarrow -1 \le \frac{2ny}{-z(t - b)} - \frac{t + b}{t - b} \le 1$

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

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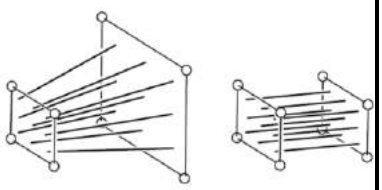
Kako domene $-1 \le \frac{2nx}{-z(r - l)} - \frac{r + l}{r - l} \le 1 \quad -1 \le \frac{2ny}{-z(t - b)} - \frac{t + b}{t - b} \le 1$

ugraditi u matricu projekcije?

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



Kako ugraditi pseudo dubinu u matricu projekcije, z_p?

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

PROJEKCIJA U PERSPEKTIVI
... OpenGL matrica projekcije

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- **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)** $1 = \frac{A*(-f)+B}{f}$

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

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

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

CLIPPING

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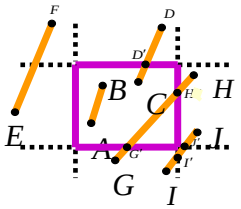
- **razlika u veličini generativne grafike i rezolucije prikaznog uređaja,**
- **clipping linije, poligona, kruga, teksta u 2D,**
- **slično u 3D samo je reč o clipping kocki,**



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.

CLIPPING

Cohen-Sutherland ...

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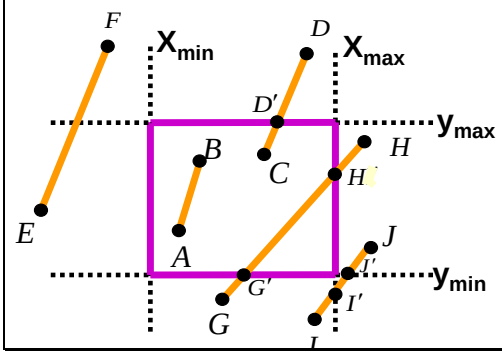
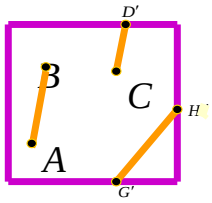
Opšta ideja algoritma:

1. **prihvati trivijalno unutr. i odbaci trivijalno spoljašnje linije,**
   $X_{maxLinija}<X_{max}$, $X_{minLinija}>X_{min}$, $Y_{maxLinija}<Y_{max}$, $Y_{minLinija}>Y_{min}$
   kako?
2. **prihvati delove ostalih linija koje se nalaze unutar prozora,**
   podela na (pri) horizontalnim (vertikalnim) linijama,





Implementacija?

Koliko selekcija?

Vreme izvršavanja?

CLIPPING

... Cohen-Sutherland ...

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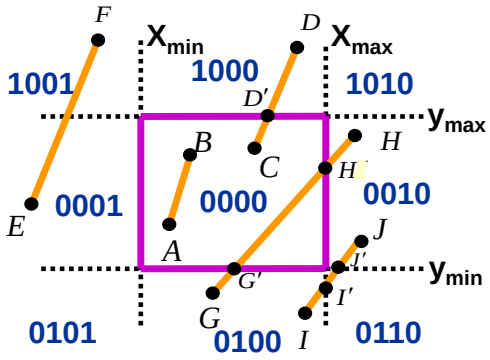
- **pametna podela ravni i njihovo kodiranje tetradama,**
- **do tetrade šiftovanjem ulevo predznaka $(y_{max}-y)$ pa $(y-y_{min})$ pa $(x_{max}-x)$ i $(x-x_{min})$, tj. iznad, ispod, udesno i ulevo,**



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

CLIPPING

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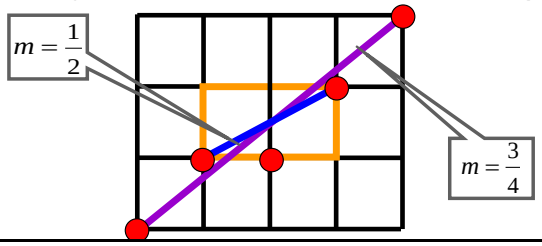
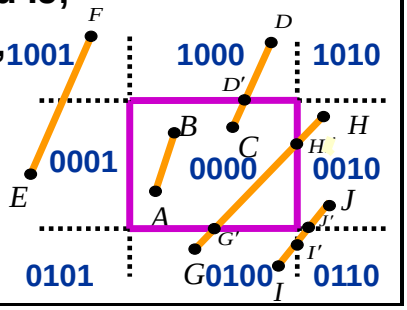
... Cohen-Sutherland

- trivijalno neprihvatljiv je (tetrada$_A$ and tetrada$_B$!= 0), a trivijalno prihvatljiv?
- kako preostale linije?
  npr. GH → 0100 and 0010 = 0000, pa se deli na
  GG$_-$' → 0100 and 0100 = 0100, trivijalno neprihvatljiv,
  G$_+$'H$_-$' → 0000 i 0000, trivijalno prihvatljiv pa u G'H',
  H$_+$'H → 0010 and 0010 = 0010, trivijalno neprihvatljiv,
- nedostatak algoritma je račun za pravu IJ,
- ukrojena kriva može imati drugi nagib,





CLIPPING

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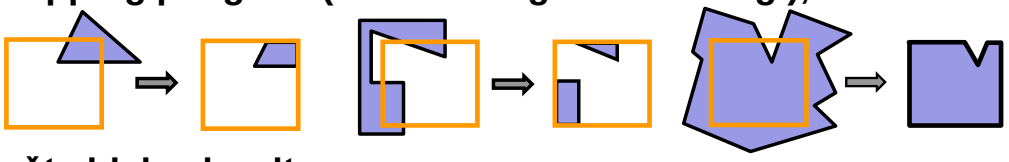
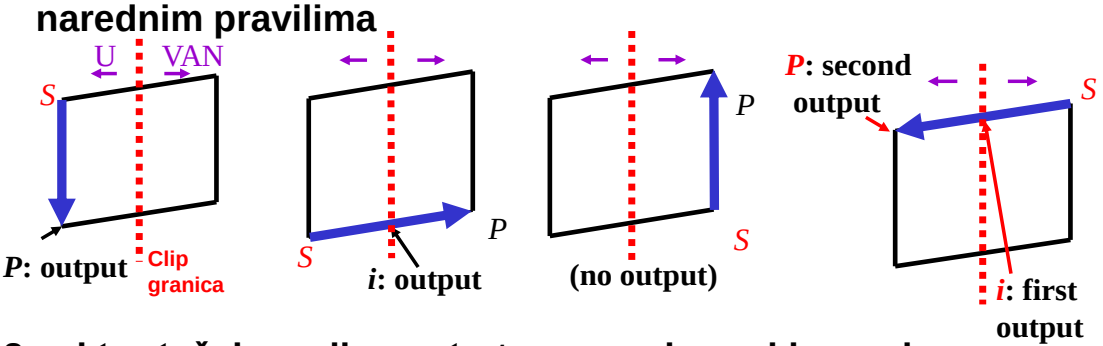
Sutherland-Hodgman ...

- clipping poligona (konveksnog i konkavnog),



Opšta ideja algoritma:

1. Clip prema beskonačnim graničnim linijama prema narednim pravilima



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

CLIPPING

... Sutherland-Hodgman ...

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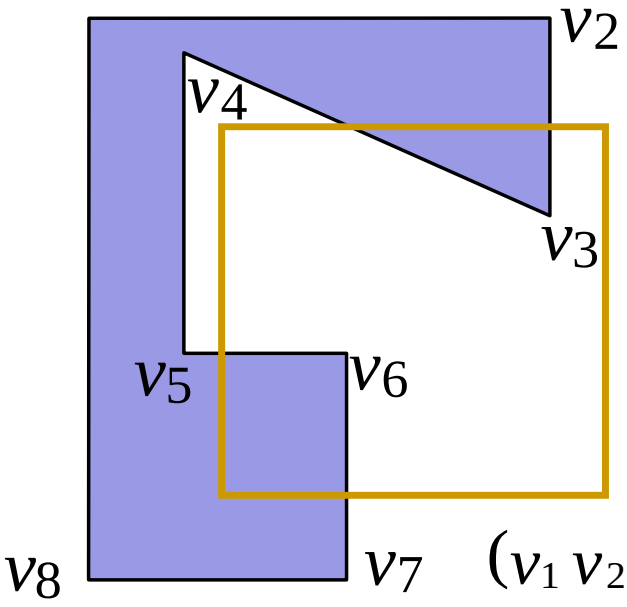

$(v_1\ v_2\ v_3\ v_4\ v_5\ v_6\ v_7\ v_8)$

CLIPPING

... Sutherland-Hodgman ...

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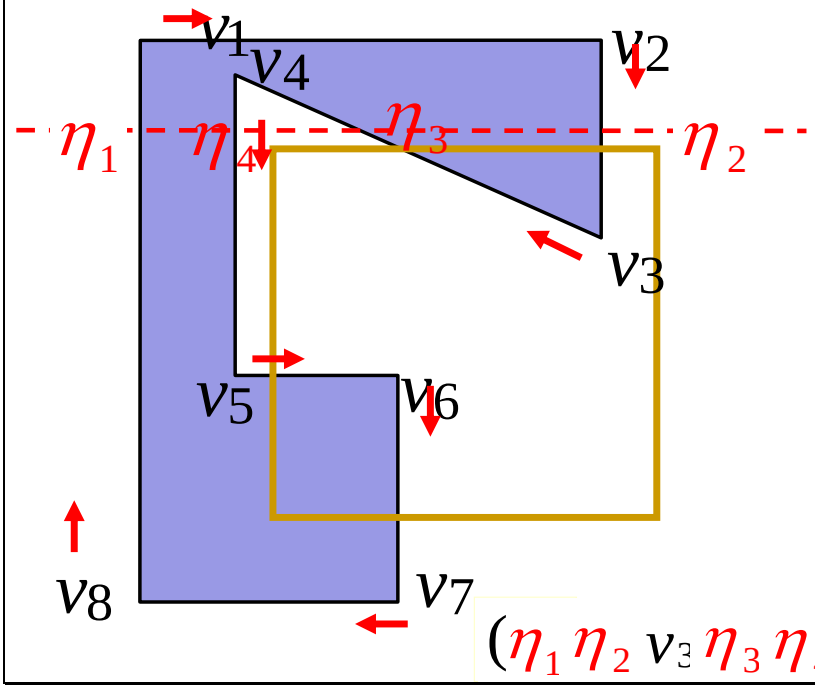

$(\eta_1\ \eta_2\ v_3\ \eta_3\ \eta_4\ v_5\ v_6\ v_7\ v_8)$

CLIPPING

... Sutherland-Hodgman ...

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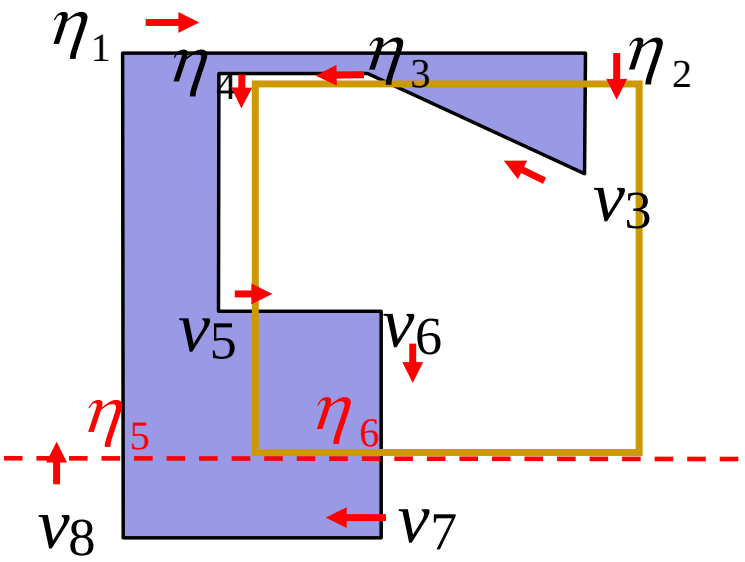

$$(\eta_5\ \eta_1\ \eta_2\ v_3\ \eta_3\ \eta_4\ v_5\ v_6\ \eta_6)$$

CLIPPING

... Sutherland-Hodgman

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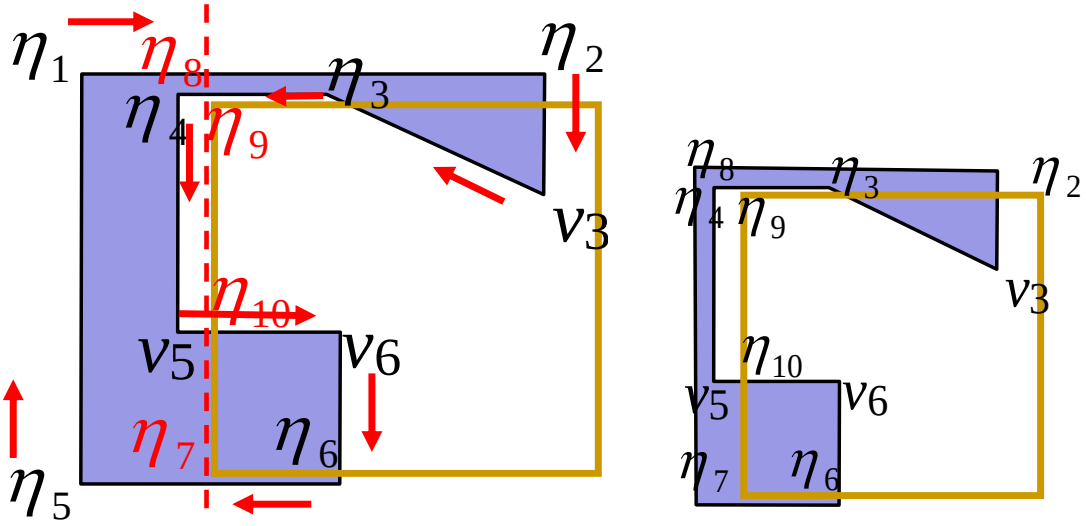
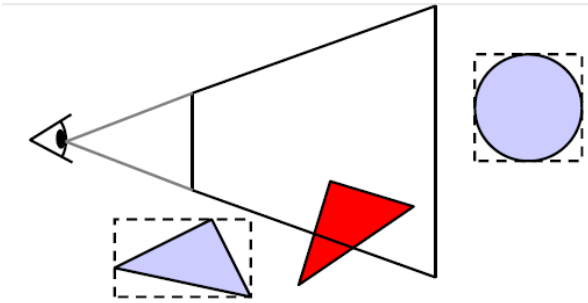


$$(\eta_7\eta_8\ \eta_2\ v_3\ \eta_3\ \eta_9\eta_{10}v_6)$$

3D CLIPPING

v.s. culling

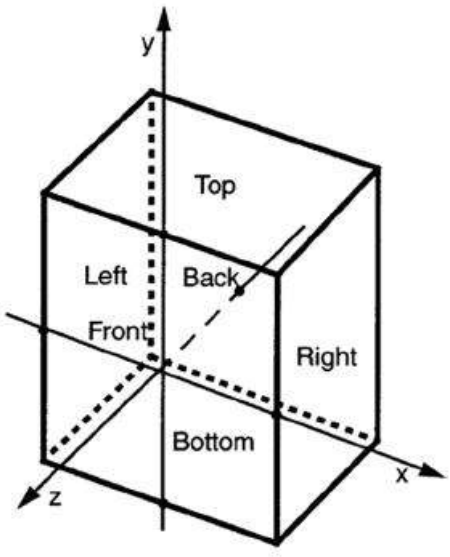


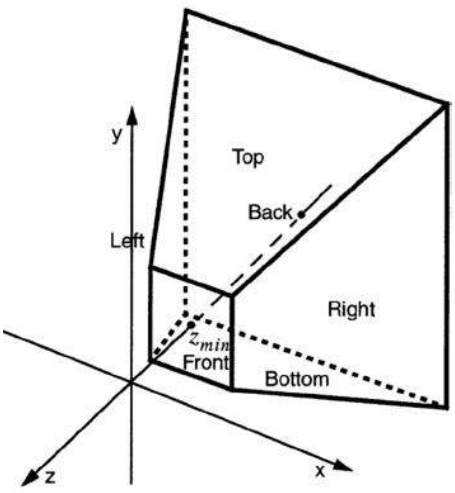
Culling:
- odbacivanje prema graničnom volumenu,
- scena = hijerarhija graničnih volumena.

Clipping:
- parcijalno vidljivi objekti se moraju iskrojiti prema datom volumenu.

3D CLIPPING

i volumeni gledanja



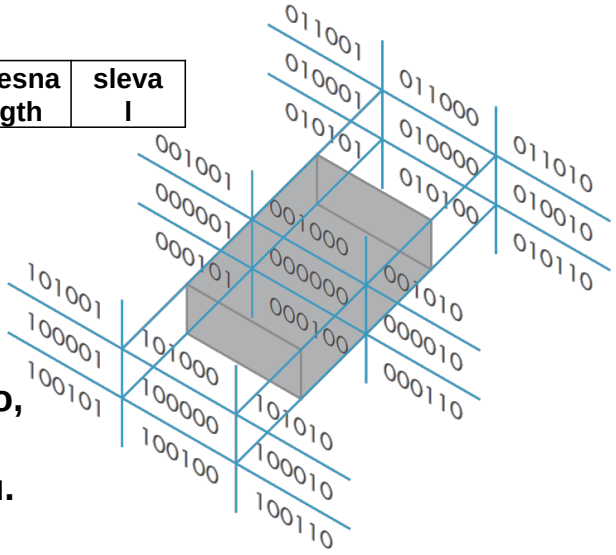


3D CLIPPING

Cohen-Sutherland

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

ispred front	iza back	iznad top	ispod bottom	sdesna rigth	sleva l



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

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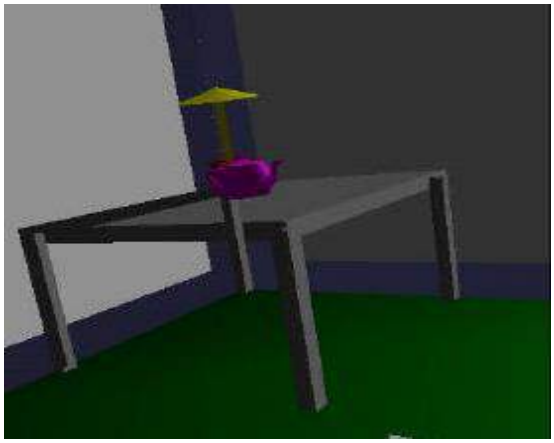
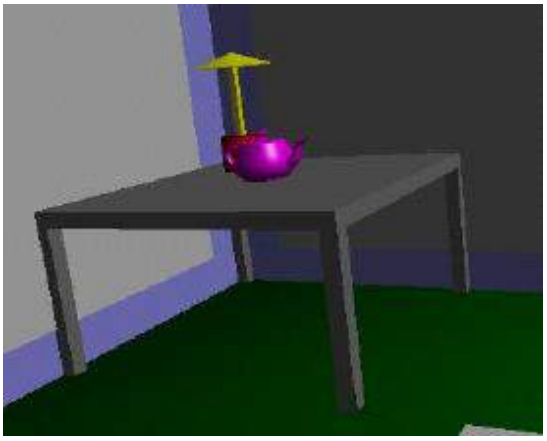
Zašto? ...

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





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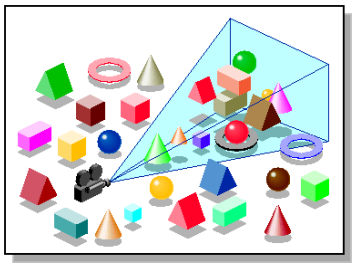
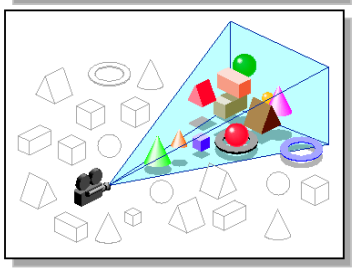
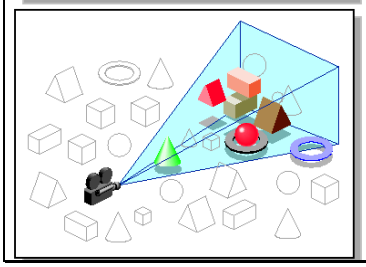
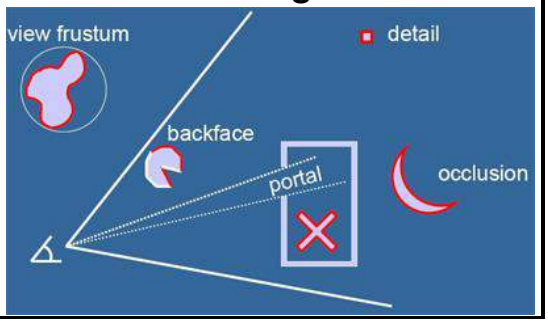
... Zašto?







- **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

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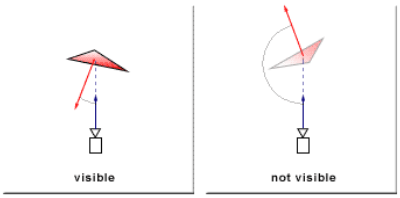
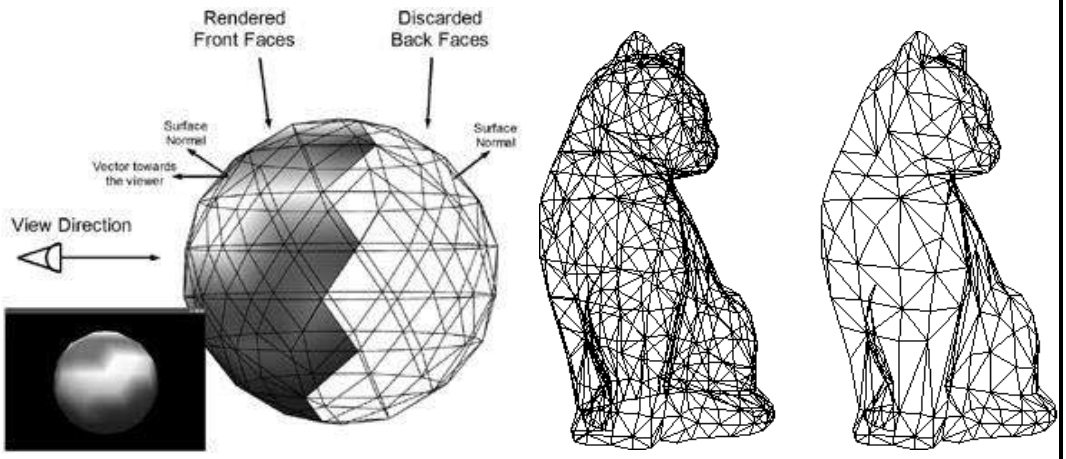
- ne prikazati površinu koja "gleda" u istom smeru kao i kamera,
- formalnije prikazati površinu akko

$$V_{kamere} \; ? \; N_{površine} \; ? \; 0.$$





UKLONI SKRIVENO

Algoritmi za uklanjanje skrivenih površina

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- da uklone (deo) površine koje su zaklonjene drugom/drugim porvšinama,

- 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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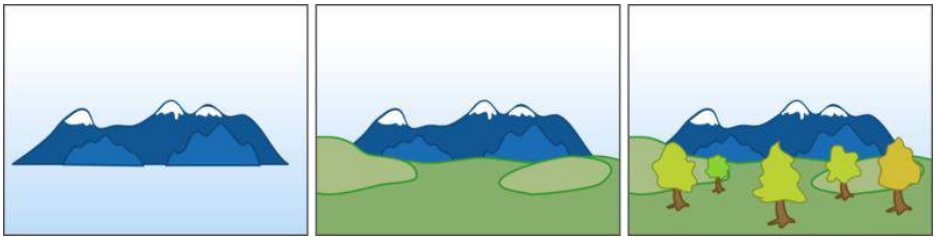
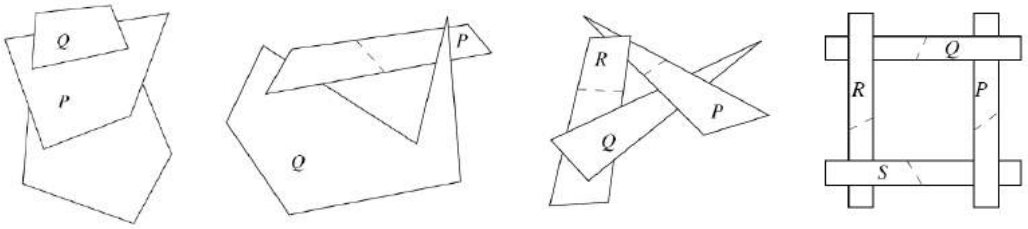
- prikazivanje površina od pozadinskih prema frontalnim,



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



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BSP stablo ...

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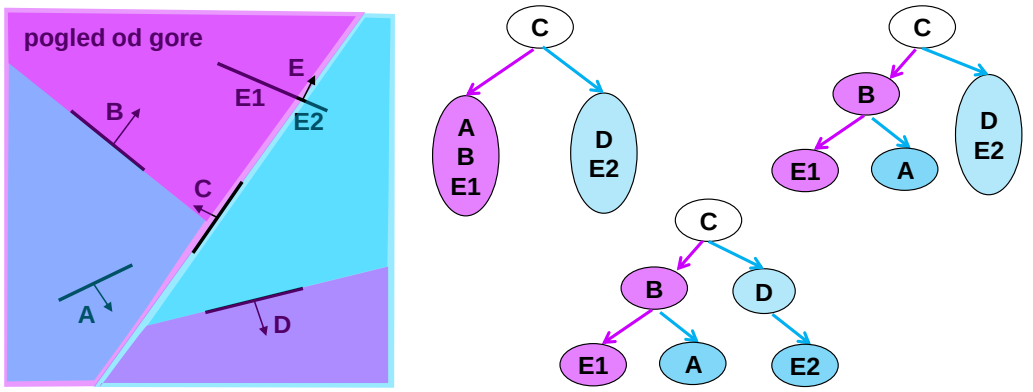
- Binary Space Partitioning tree,
- prostor se deli na ispred / iza ravni koja sadrži poligon,
- ako ravan preseca neki drugi poligon, on se deli na dva potpoligona...,
- nastaviti dok svaki čvor stabla bude jedan poligon,
- takvo stablo će definisati redosled prikaza poligona,



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... BSP stablo

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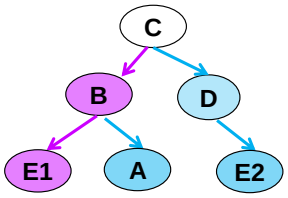
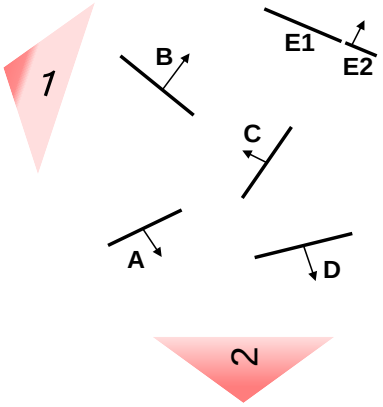
- kako prolaziti kroz stablo do liste redosleda prikaza?
- gledalac ispred → potprostor desnog podstabla, koren, potprostor levog podstabla,
- gledalac iza → potprostor levog podstabla, koren, potprostor desnog podstabla,
- gledalac na granici → ?

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





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Portal culling

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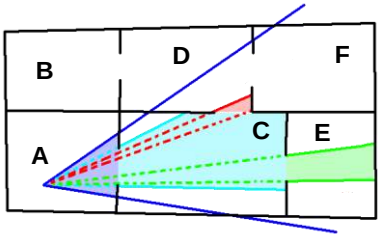
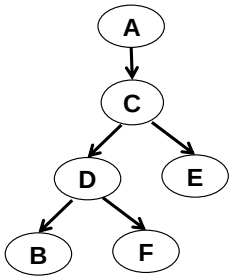
- zasnovan na grafu ćelija i portala (vrata),
- prvo se renderuje ćelija gde je posmatrač, pa onda onoliko koliko se vidi kroz portale...





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Z-buffer ...

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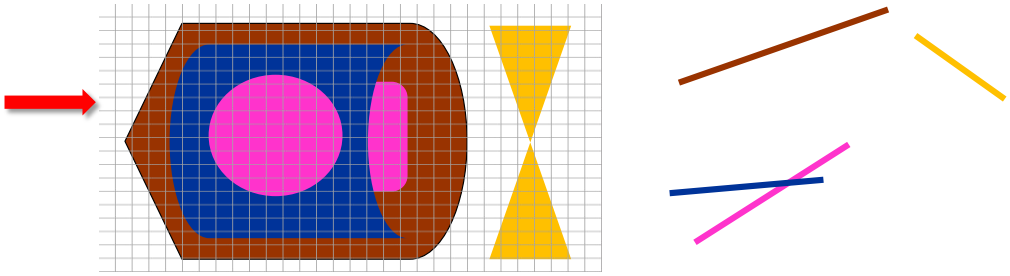
- image-space tehnika,
- osnovna ideja Z-buffer:
  - inicijalno Z-buffer elementi na -1,
  - rasterizuj svaki ulazni poligon,
    - za svaki piksel interijera, interpoliraj njegov Z,
    - upiši (Z vrednost i) boju u njegov deo bafera akko je Z veća od postojeće u baferu,
  - prikaži vrednosti boja iz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



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... Z buffer ...

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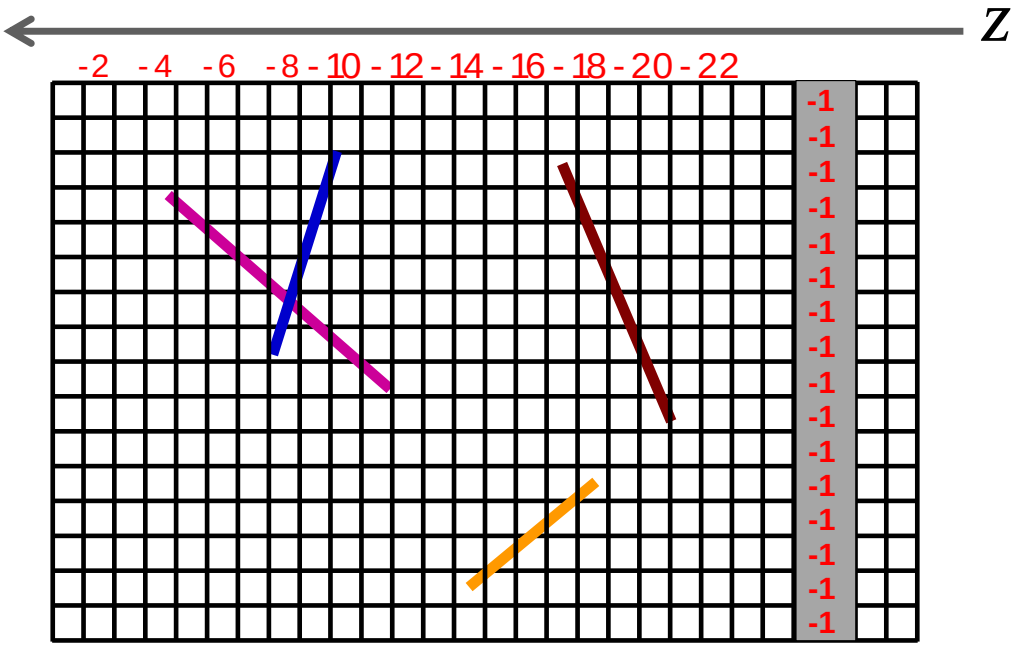

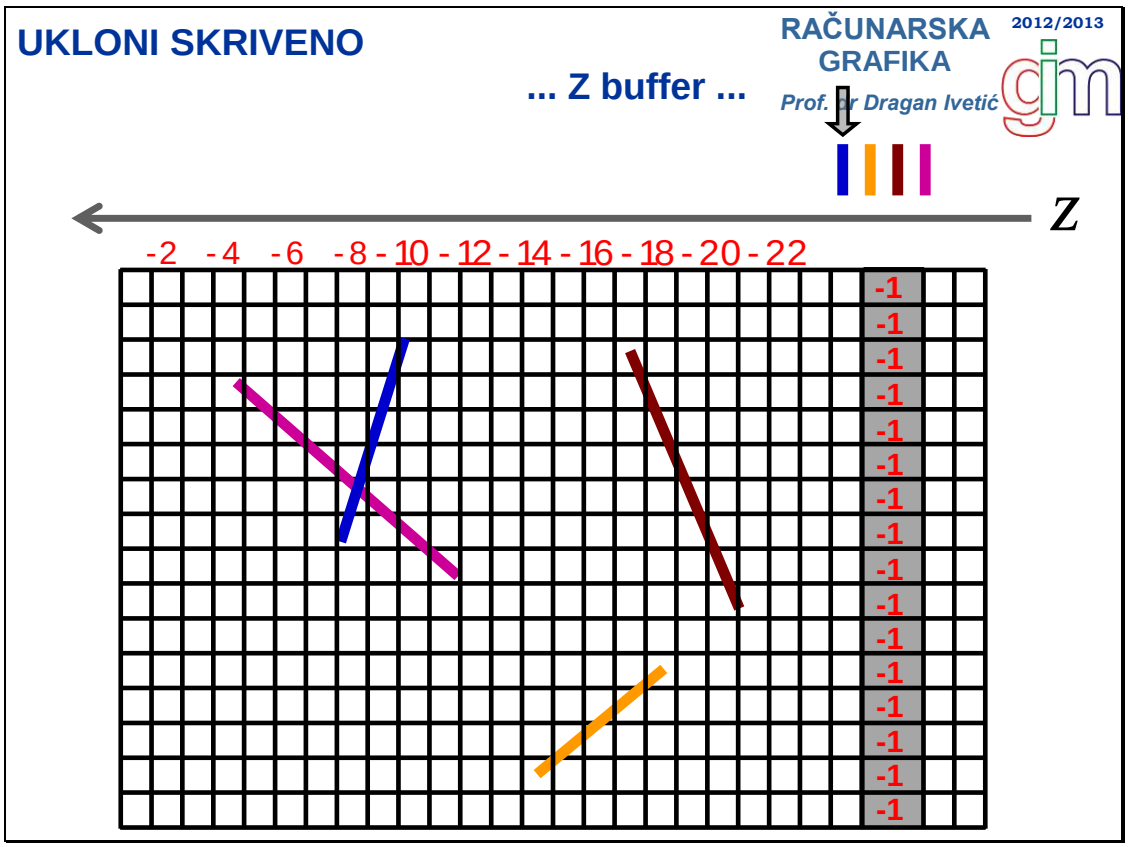
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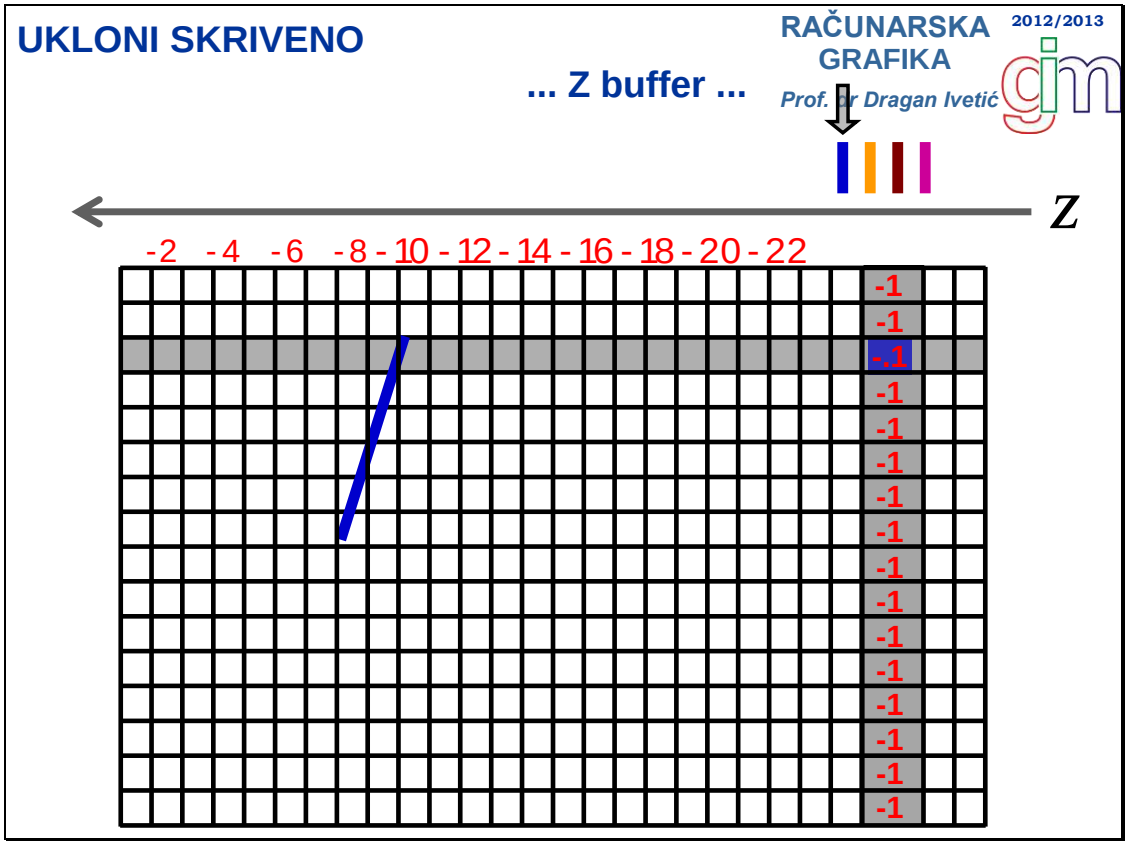
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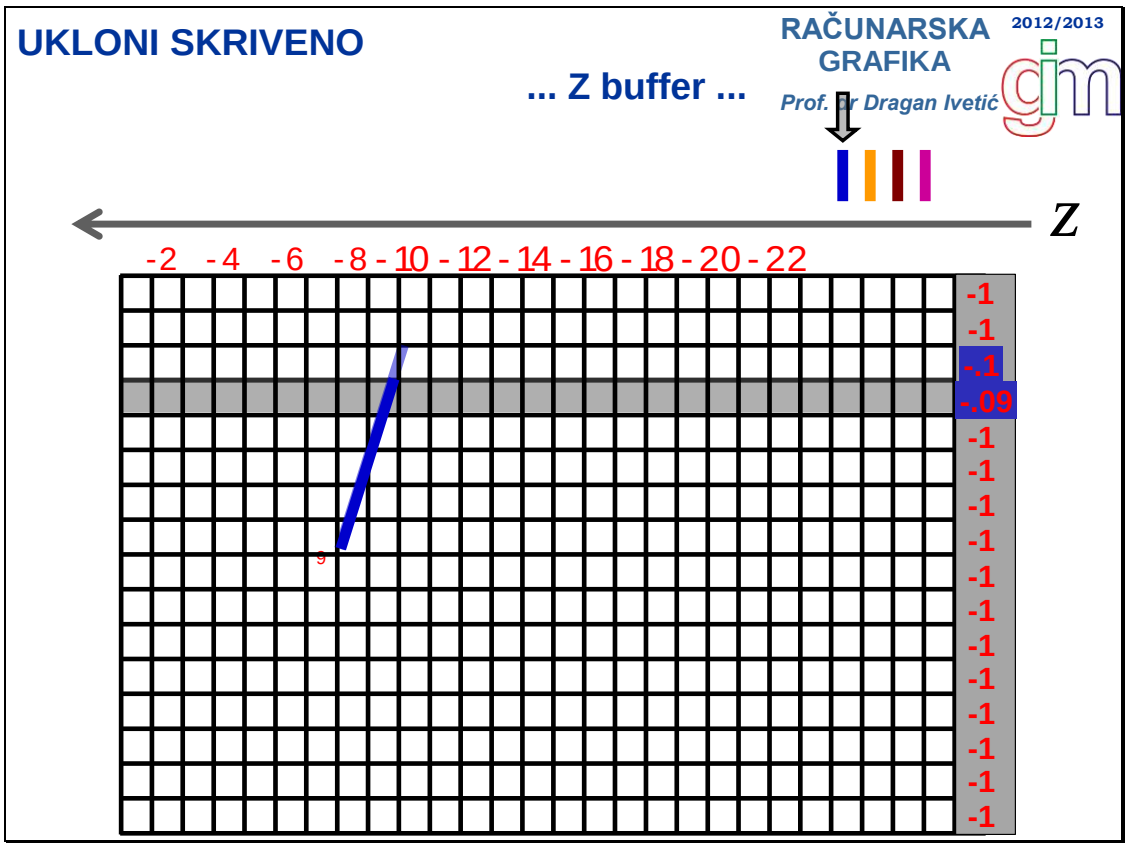
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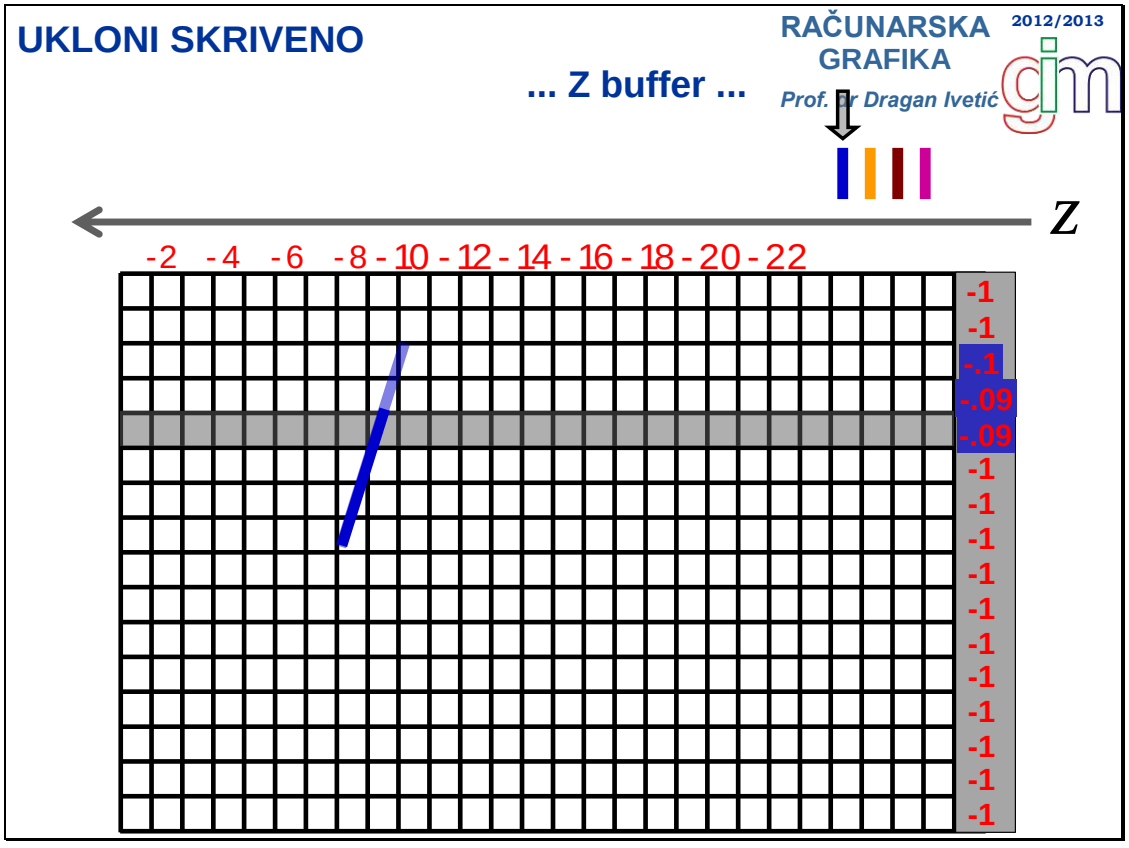
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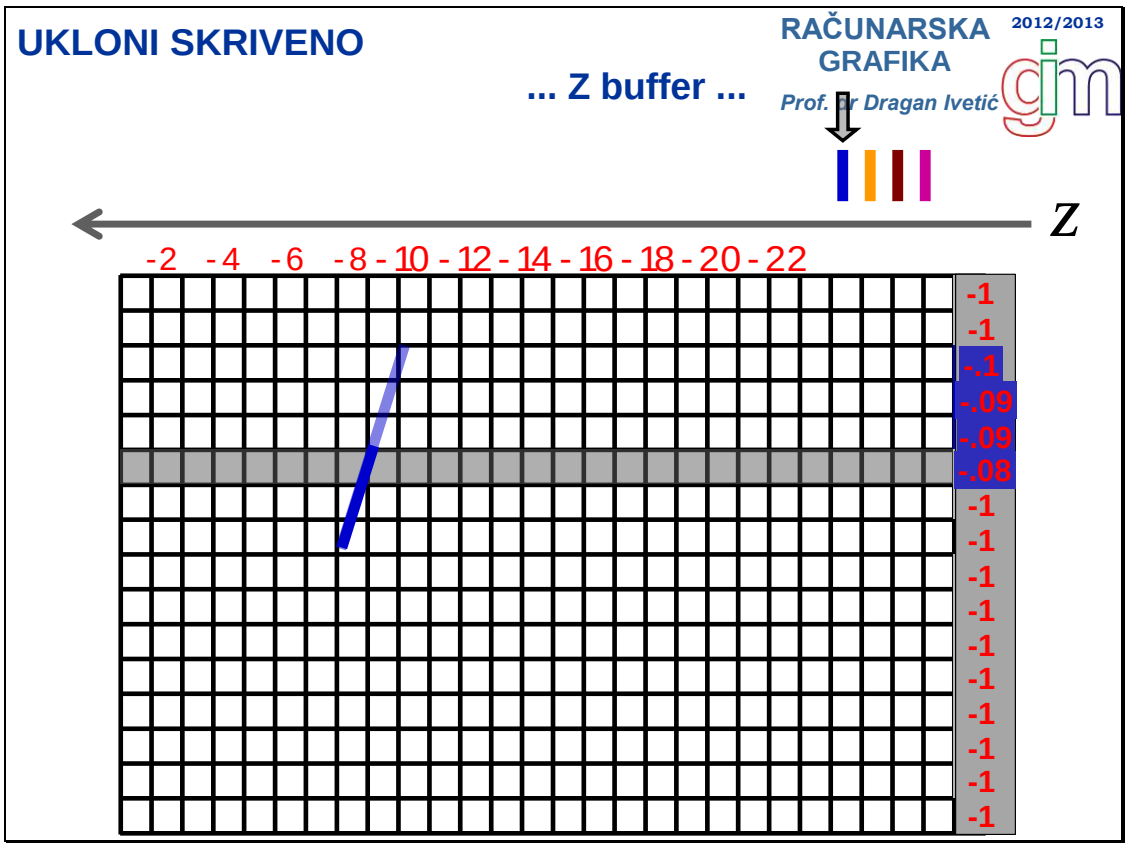
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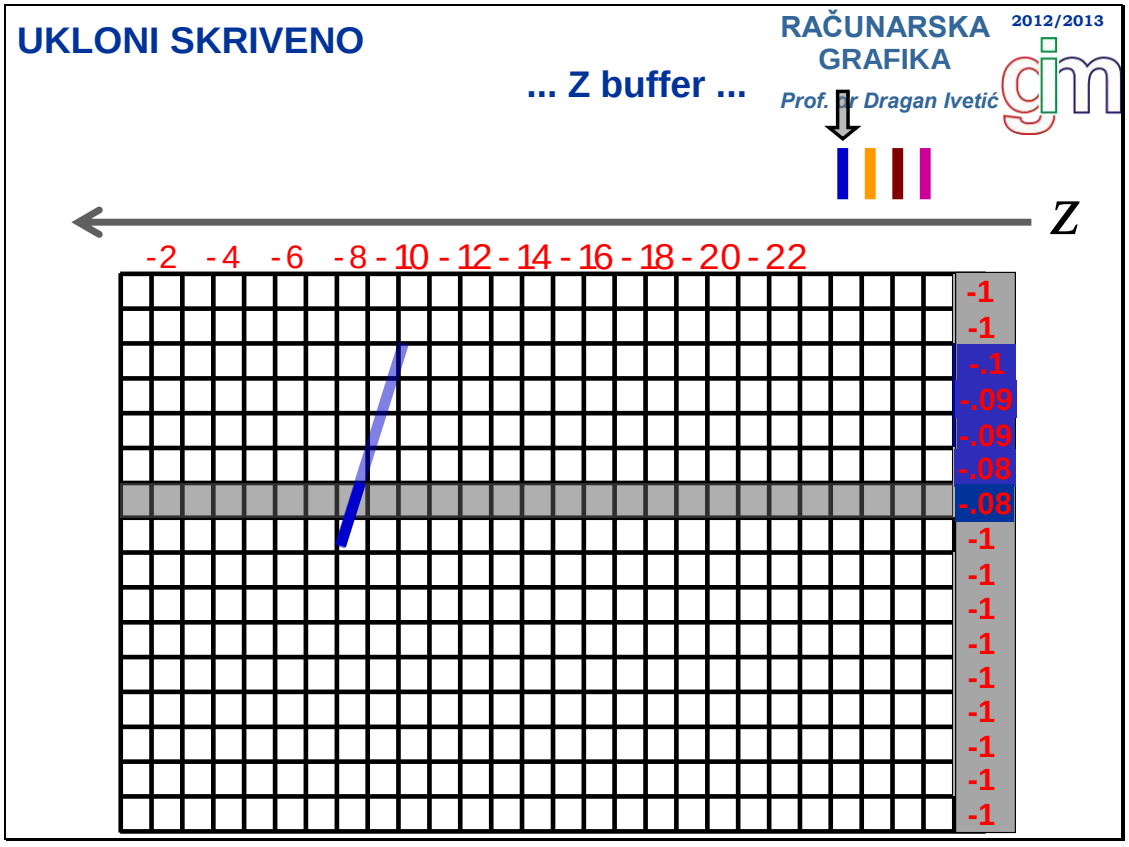
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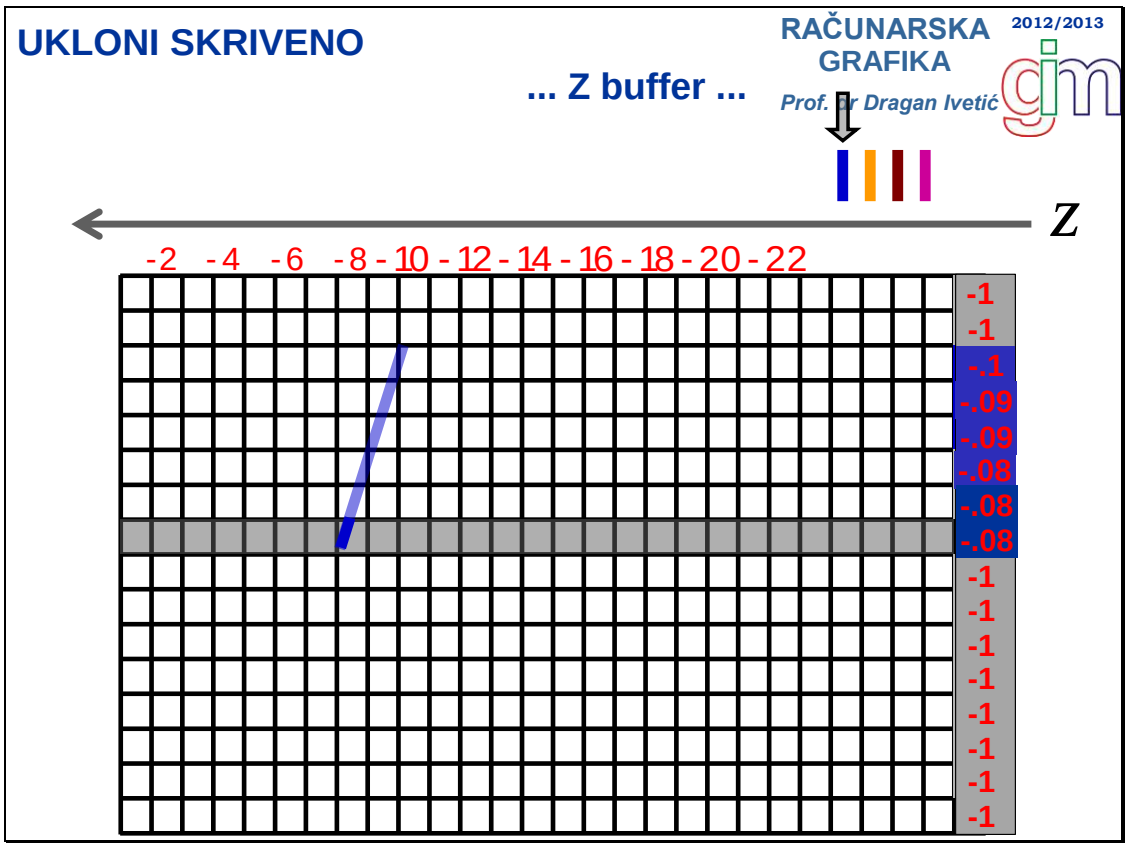
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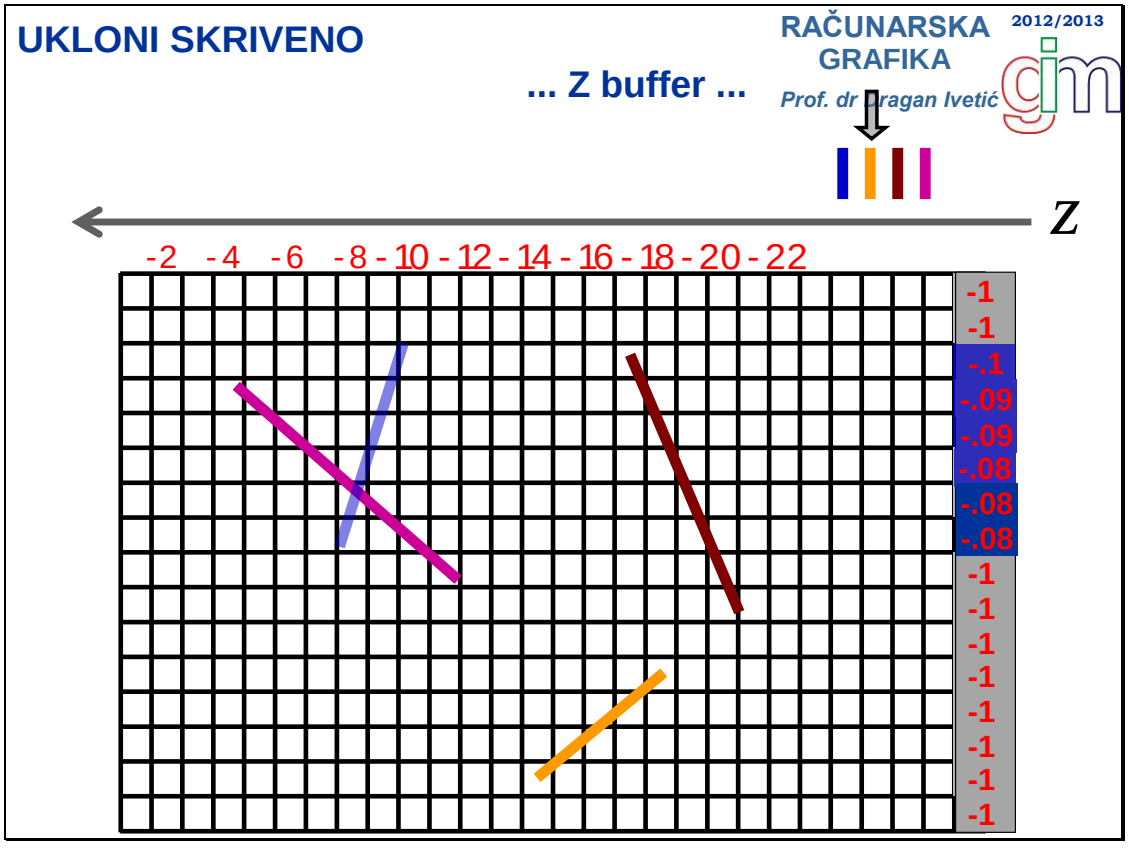
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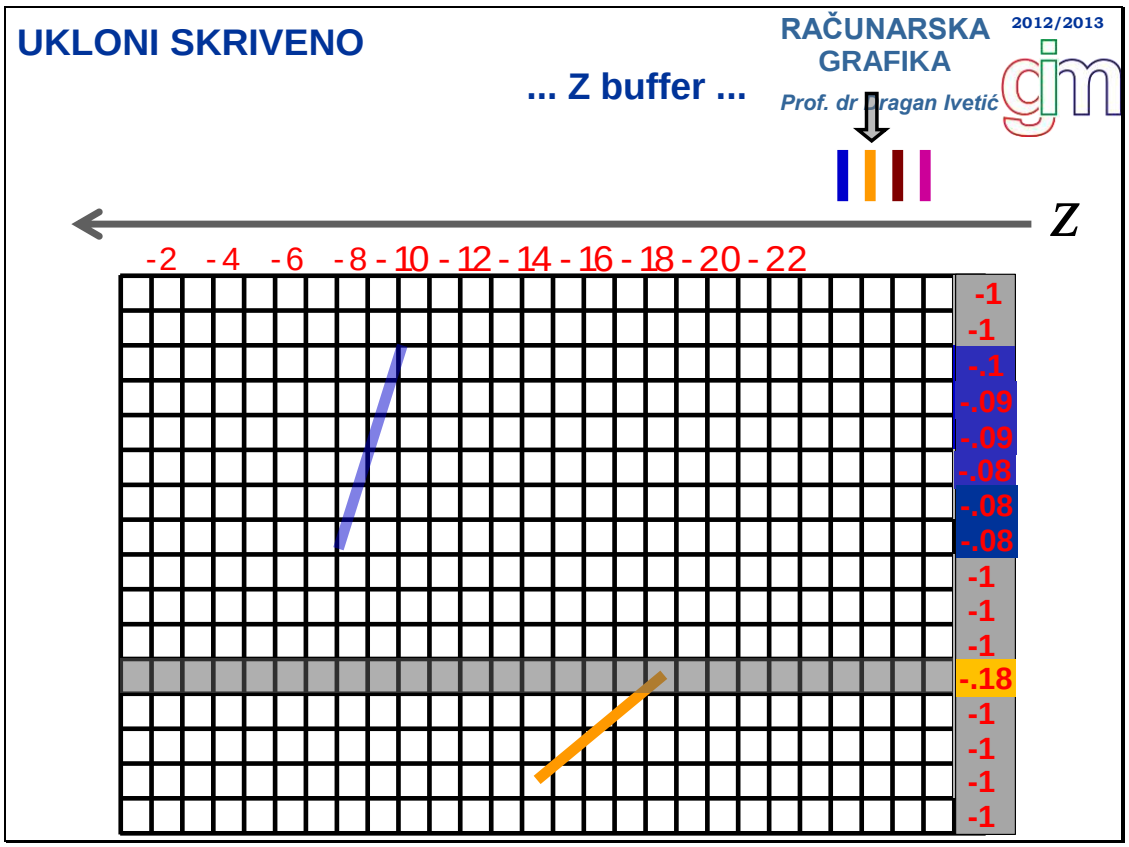
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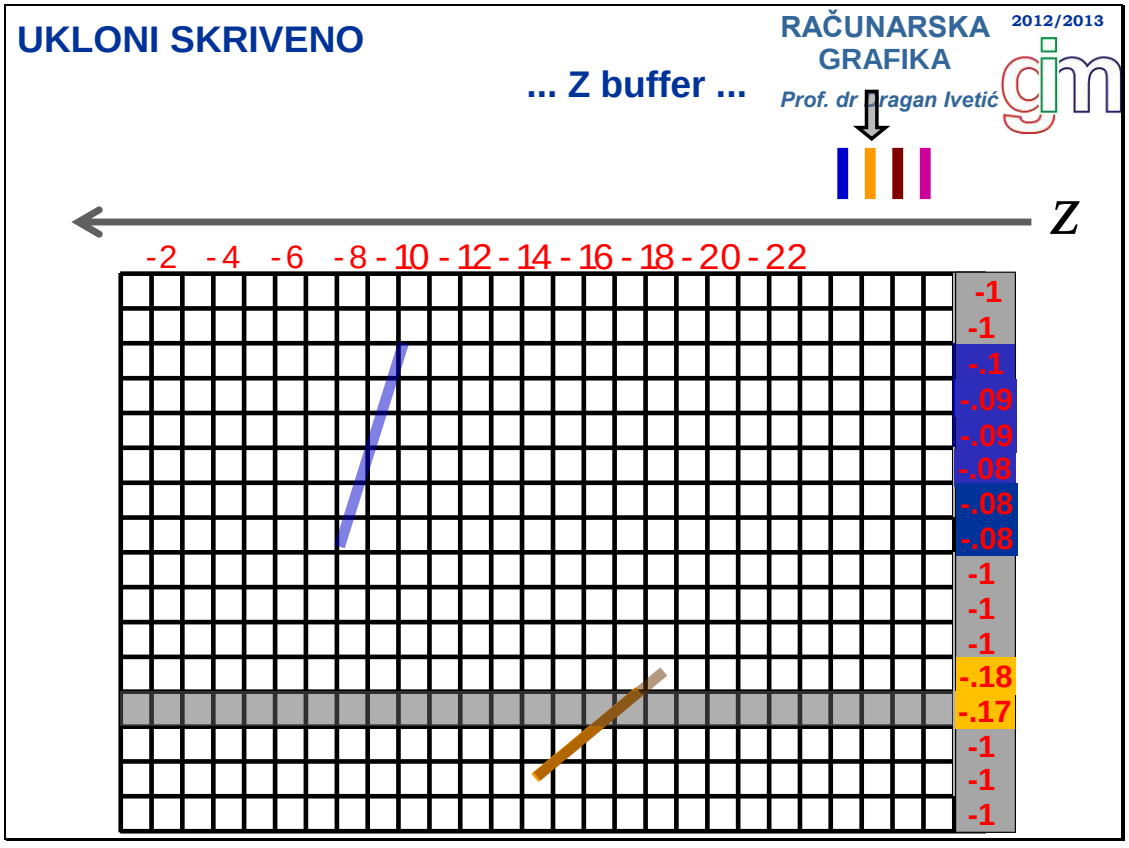
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RAČUNARSKA GRAFIKA
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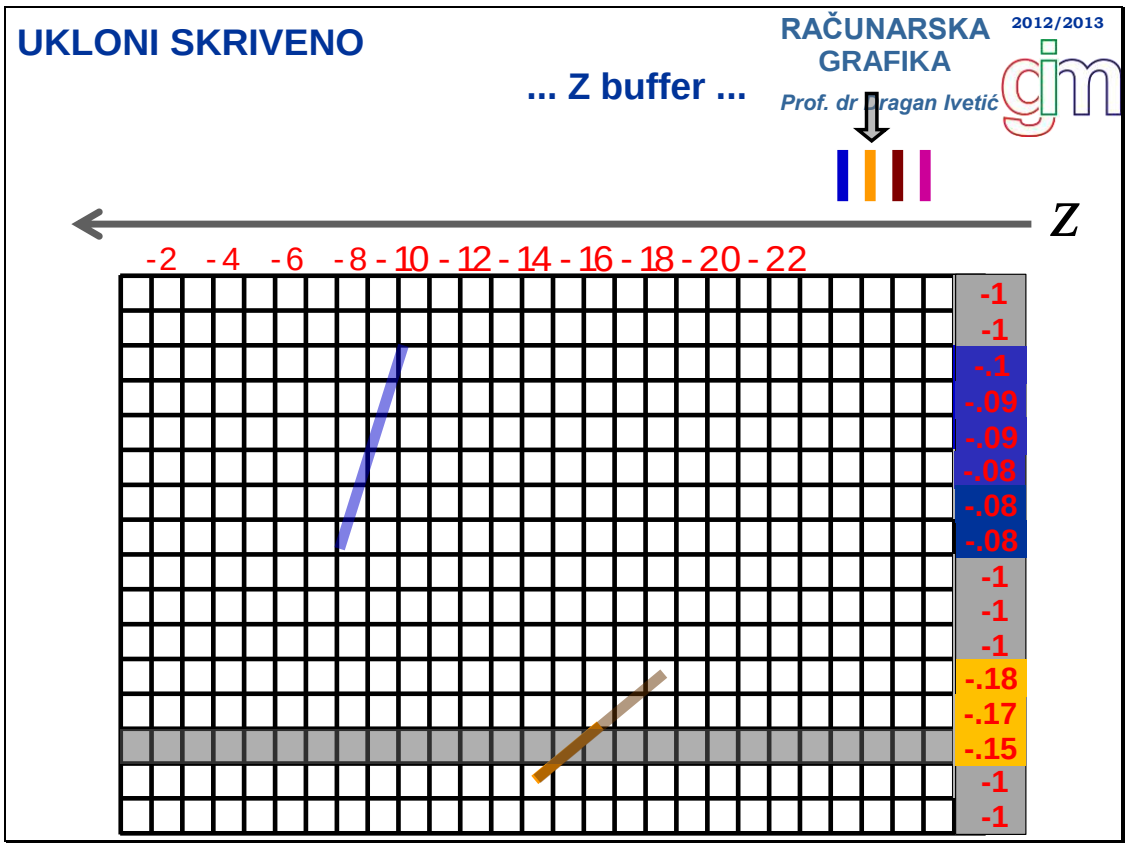
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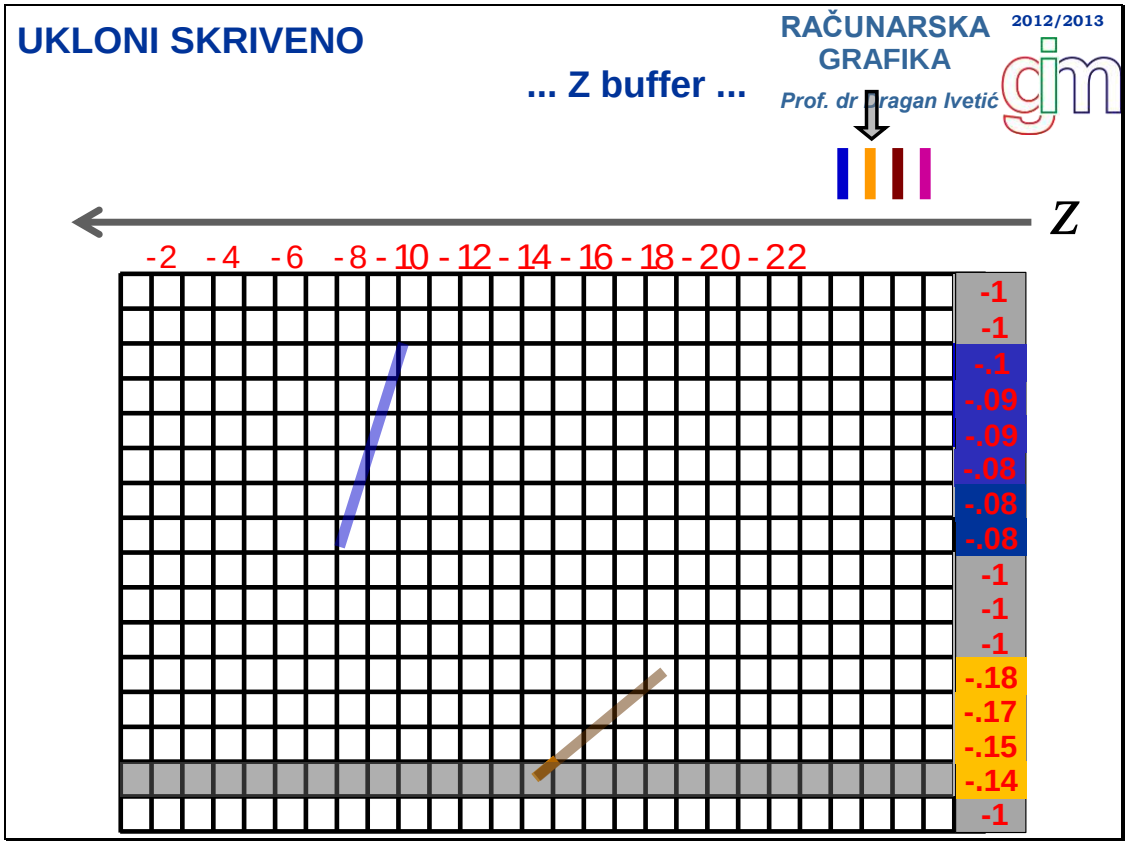
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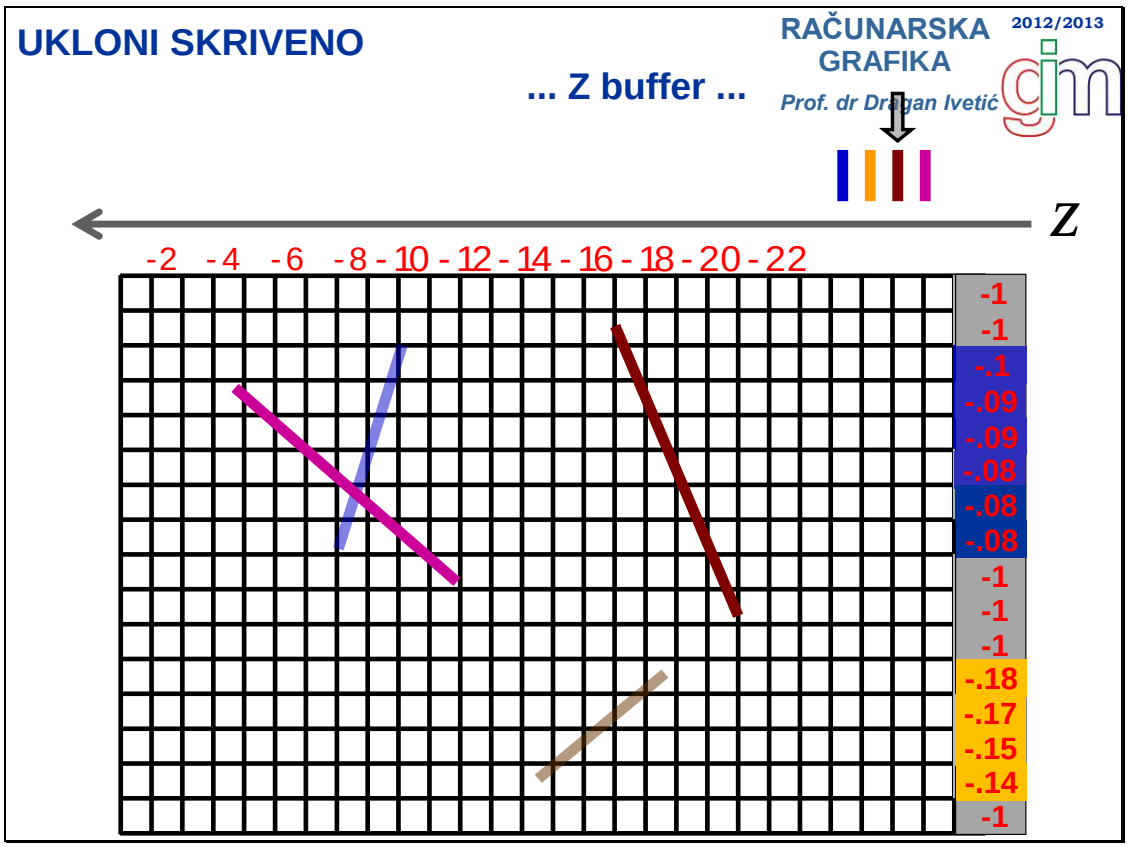
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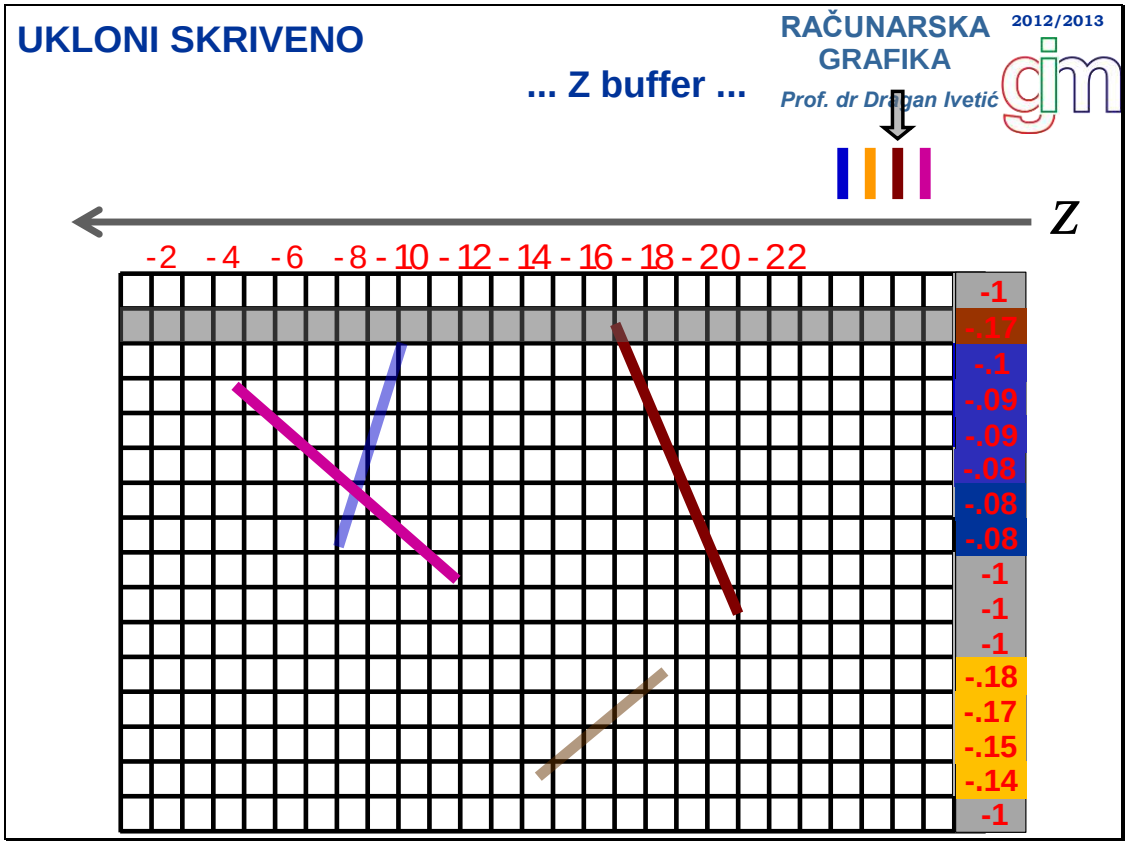
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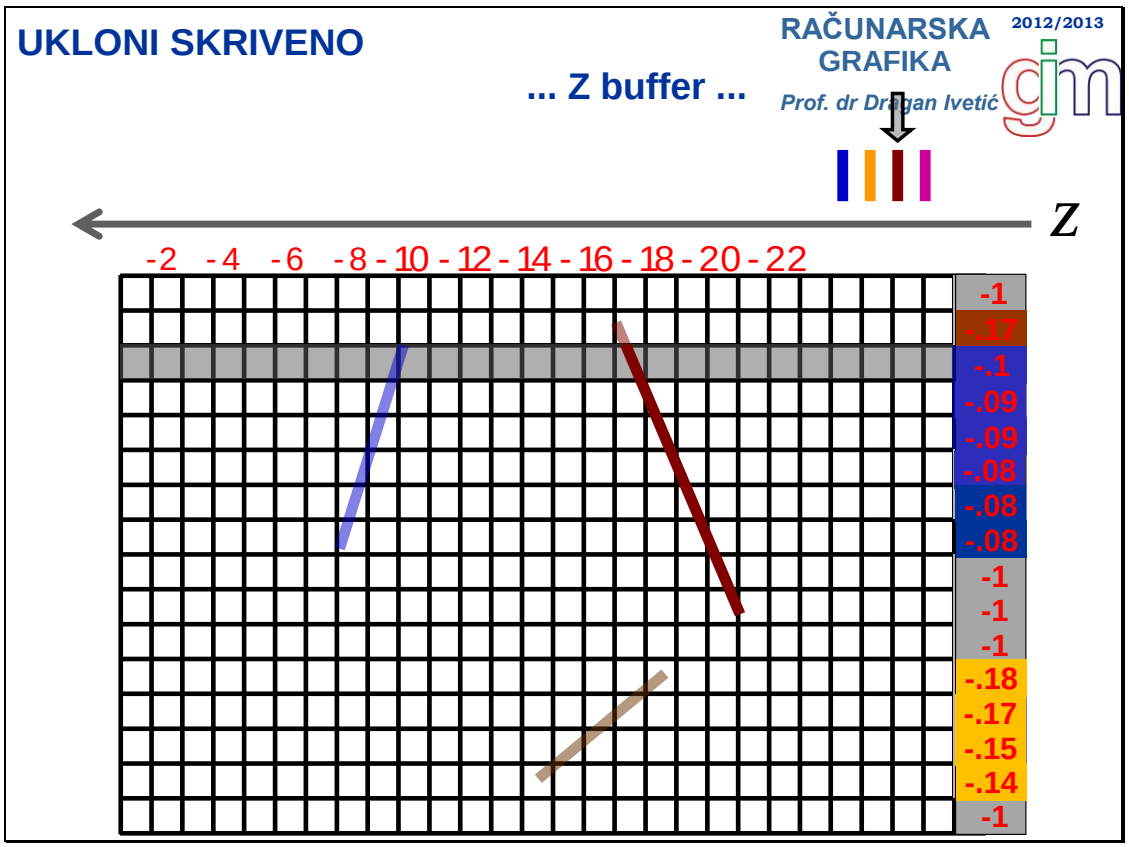
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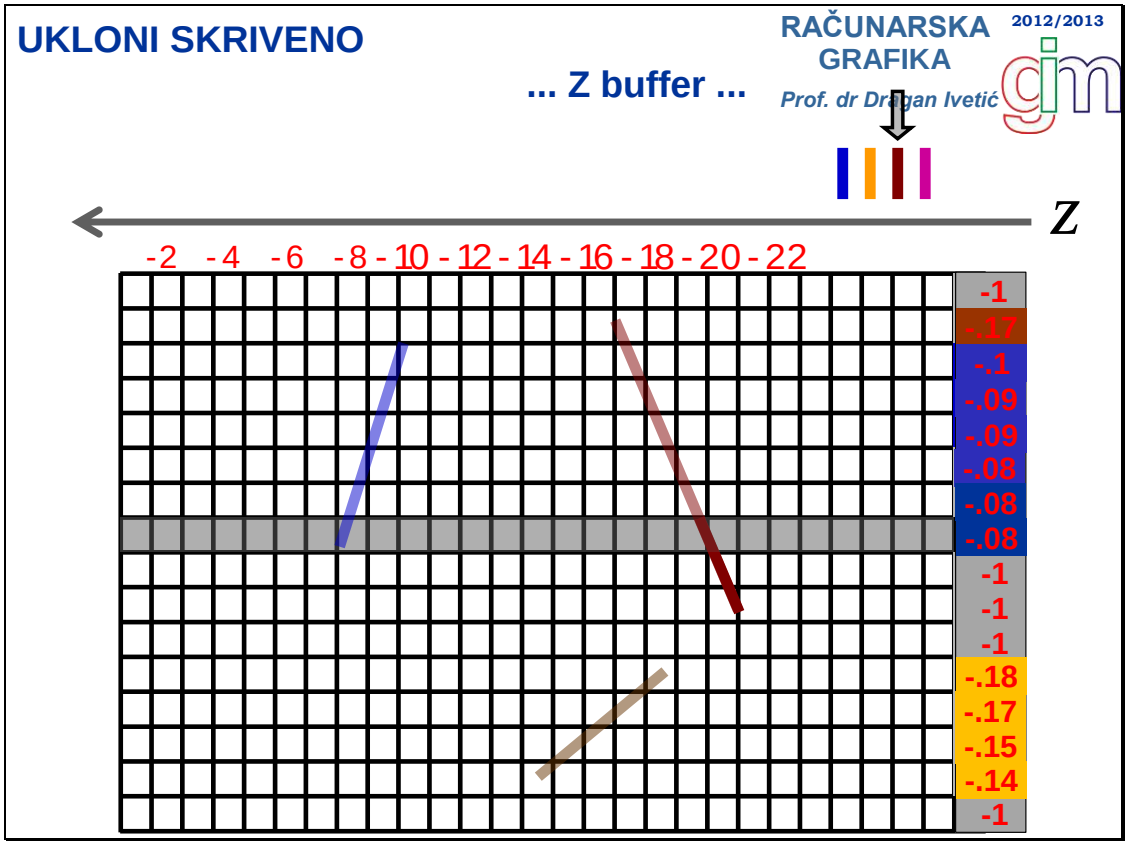
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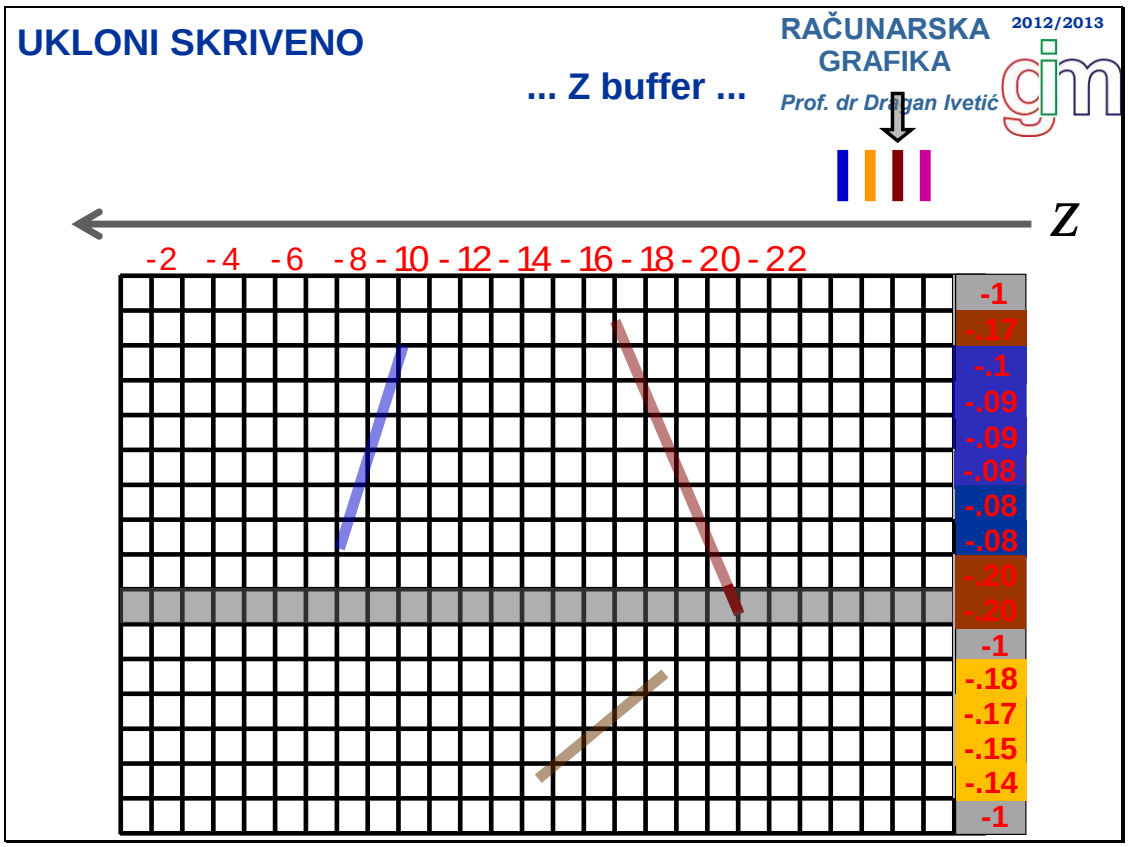
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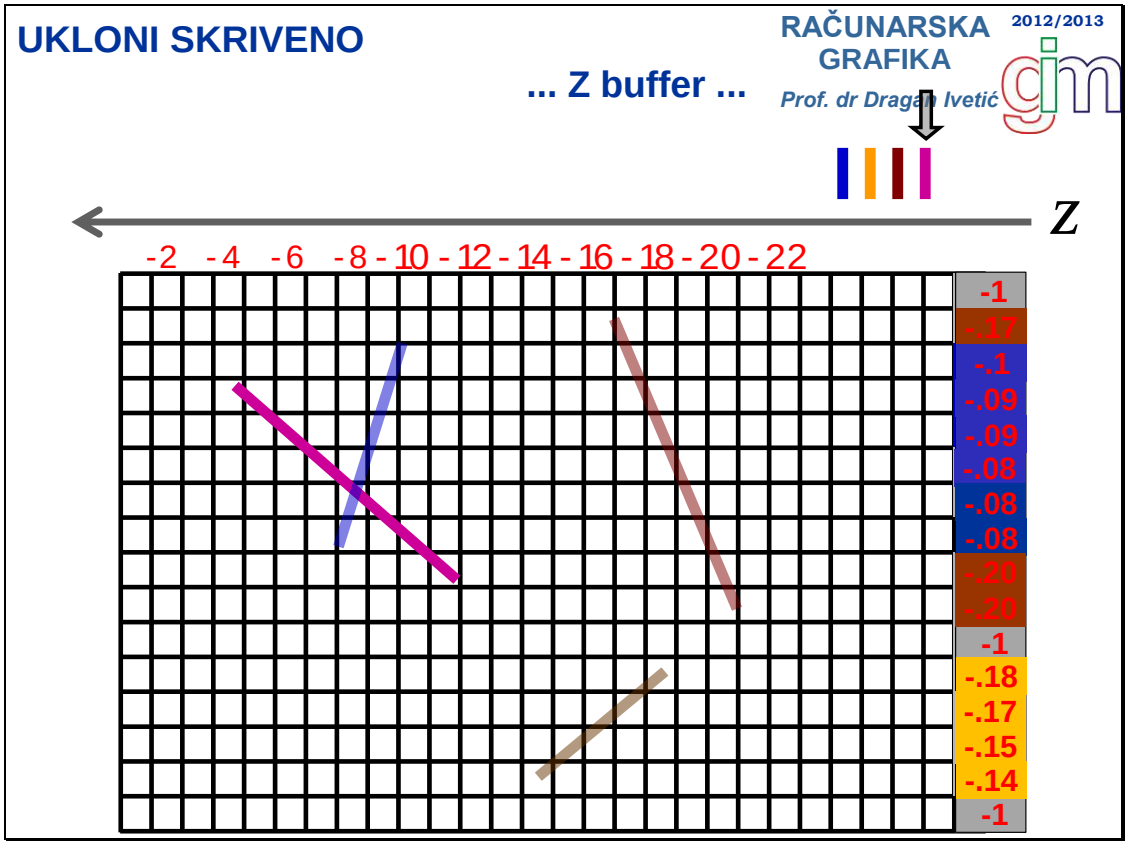
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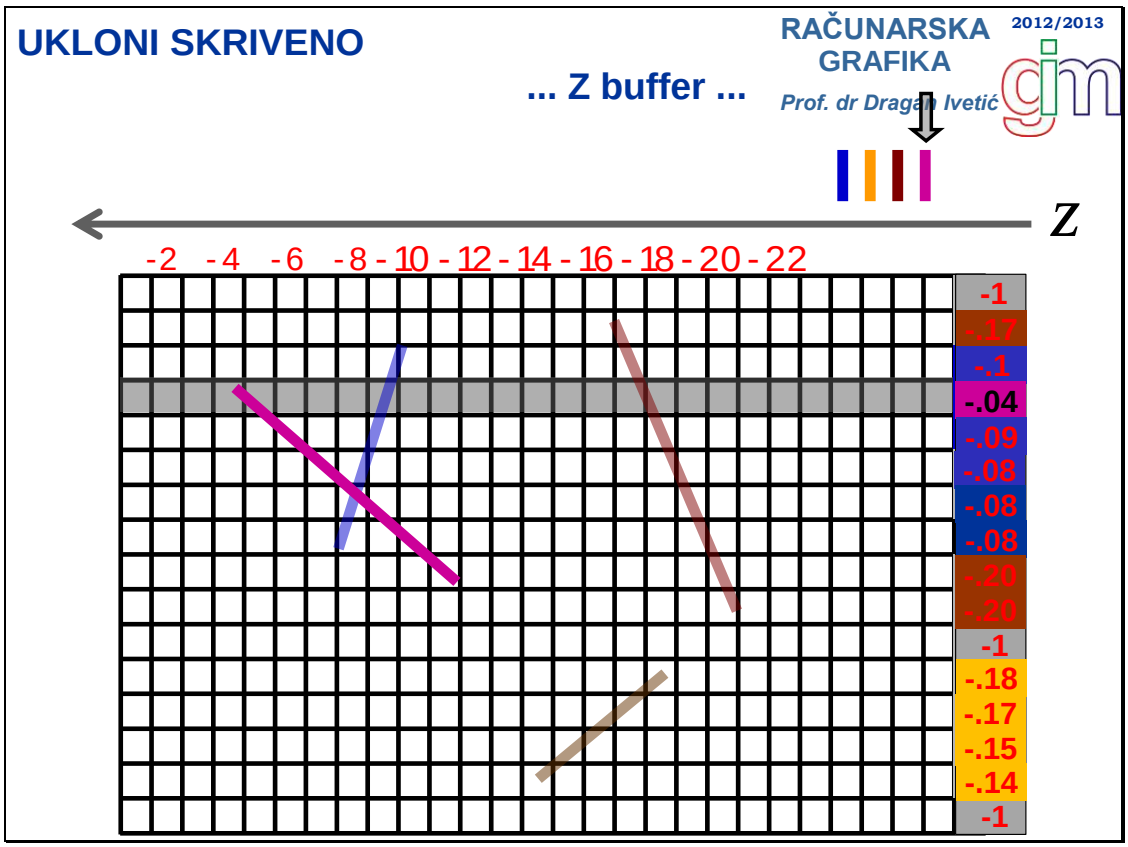
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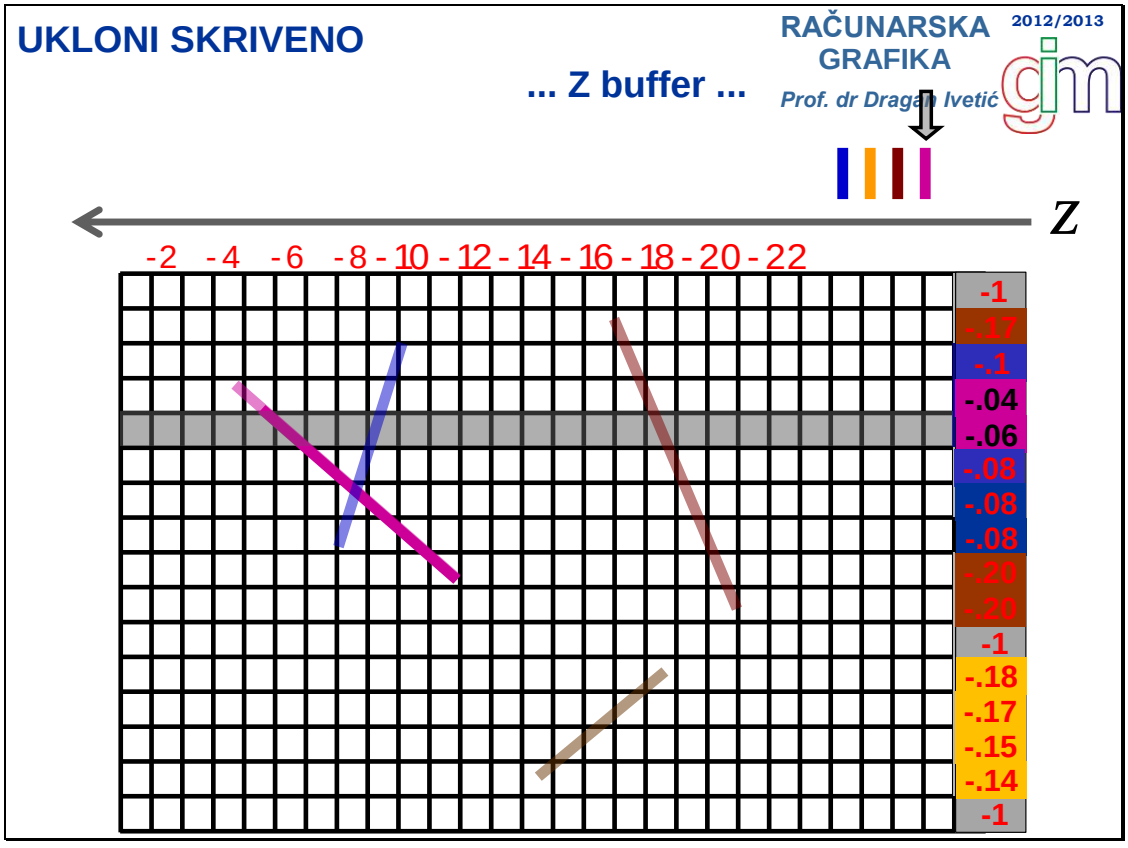
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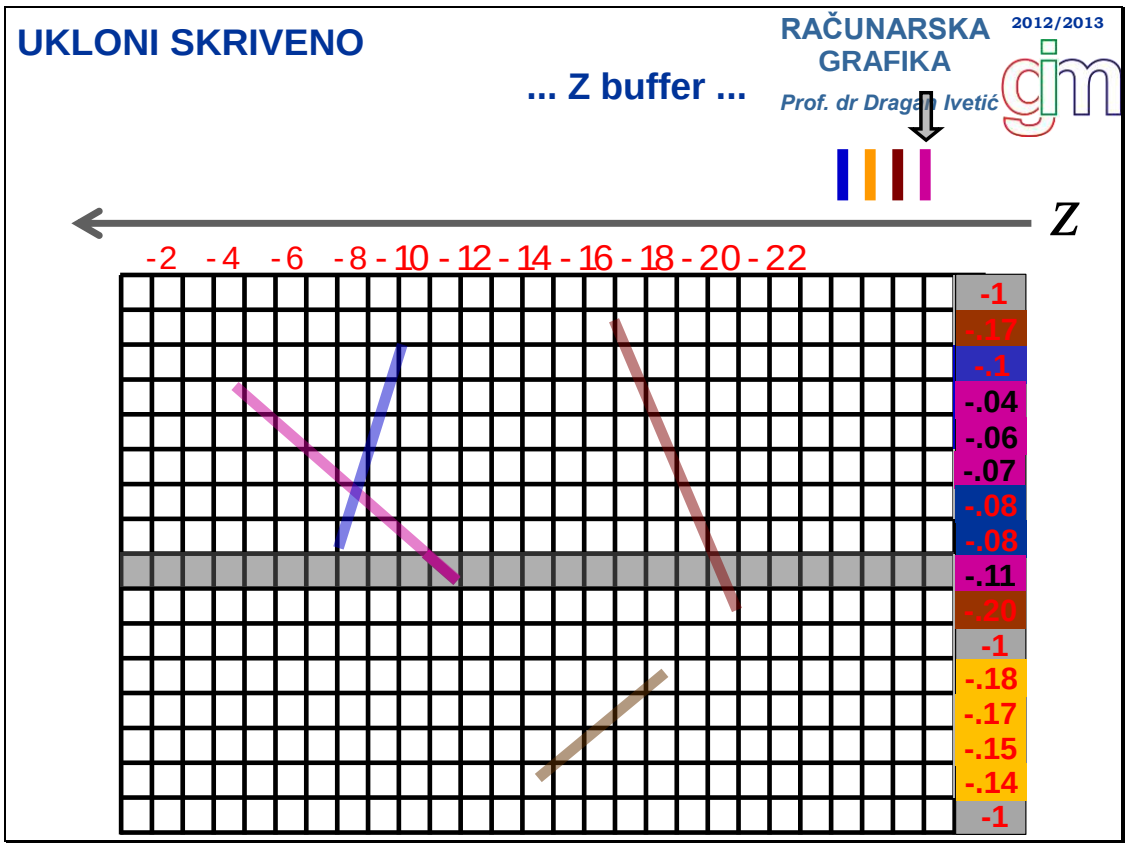
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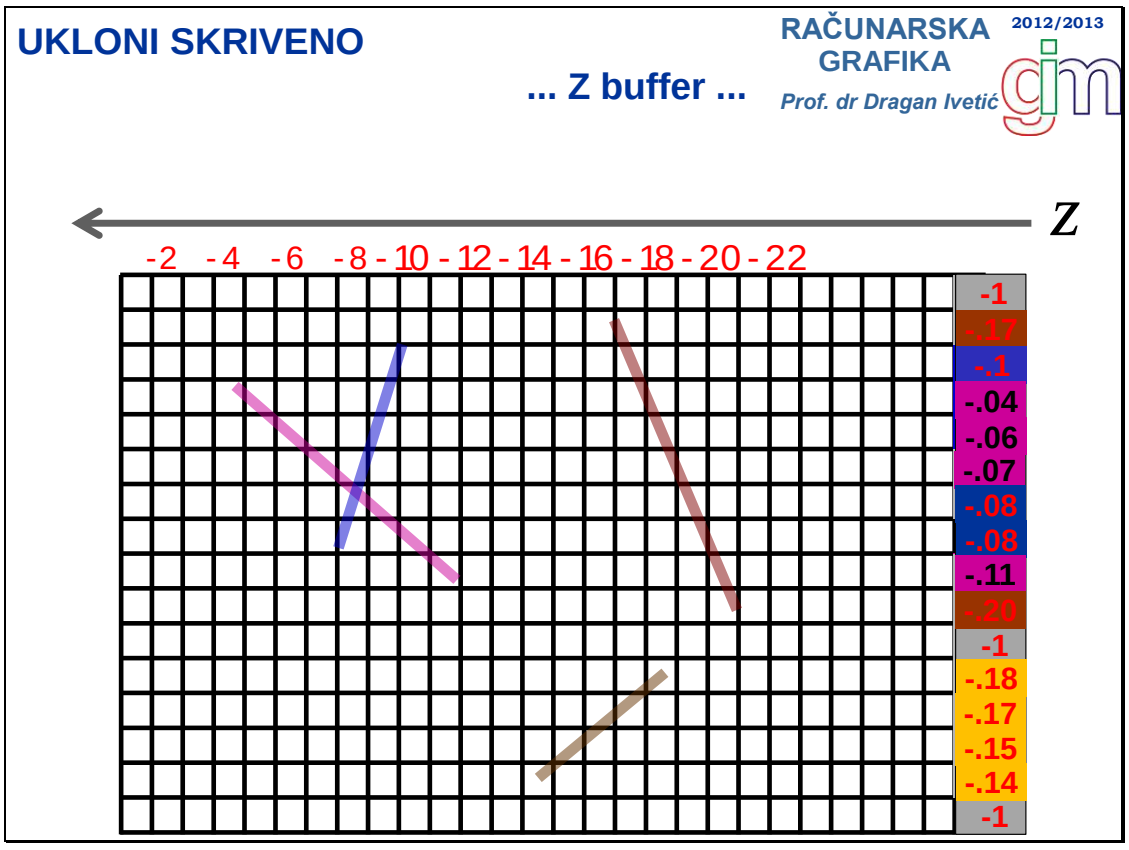
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UKLONI SKRIVENO

... Z buffer ...

RAČUNARSKA GRAFIKA 2012/2013
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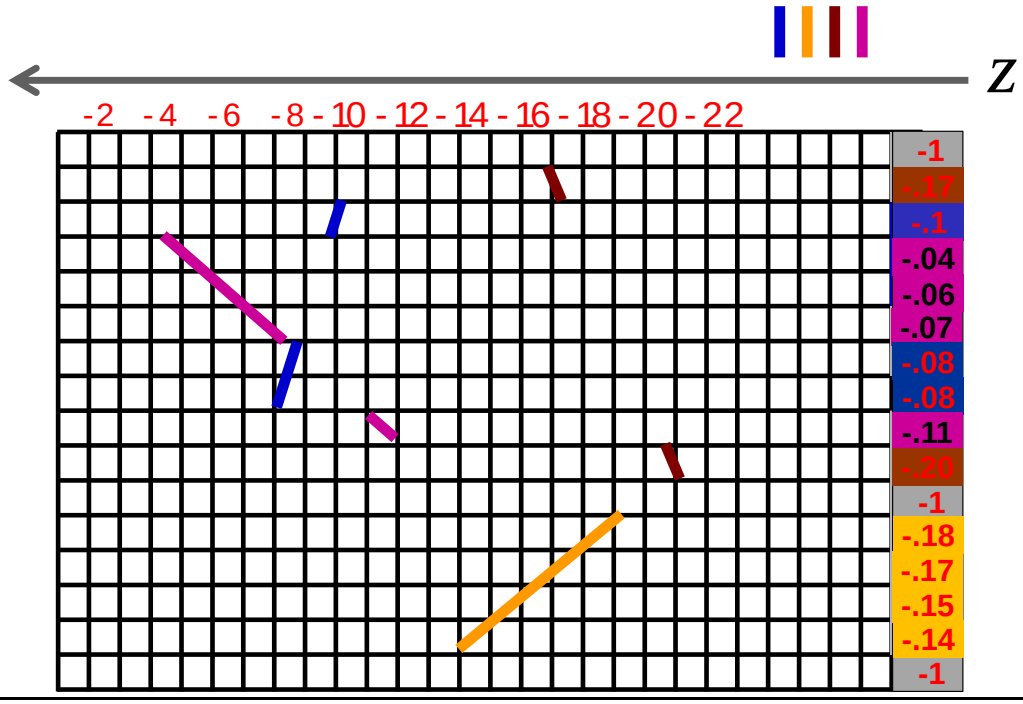

UKLONI SKRIVENO

... Z buffer

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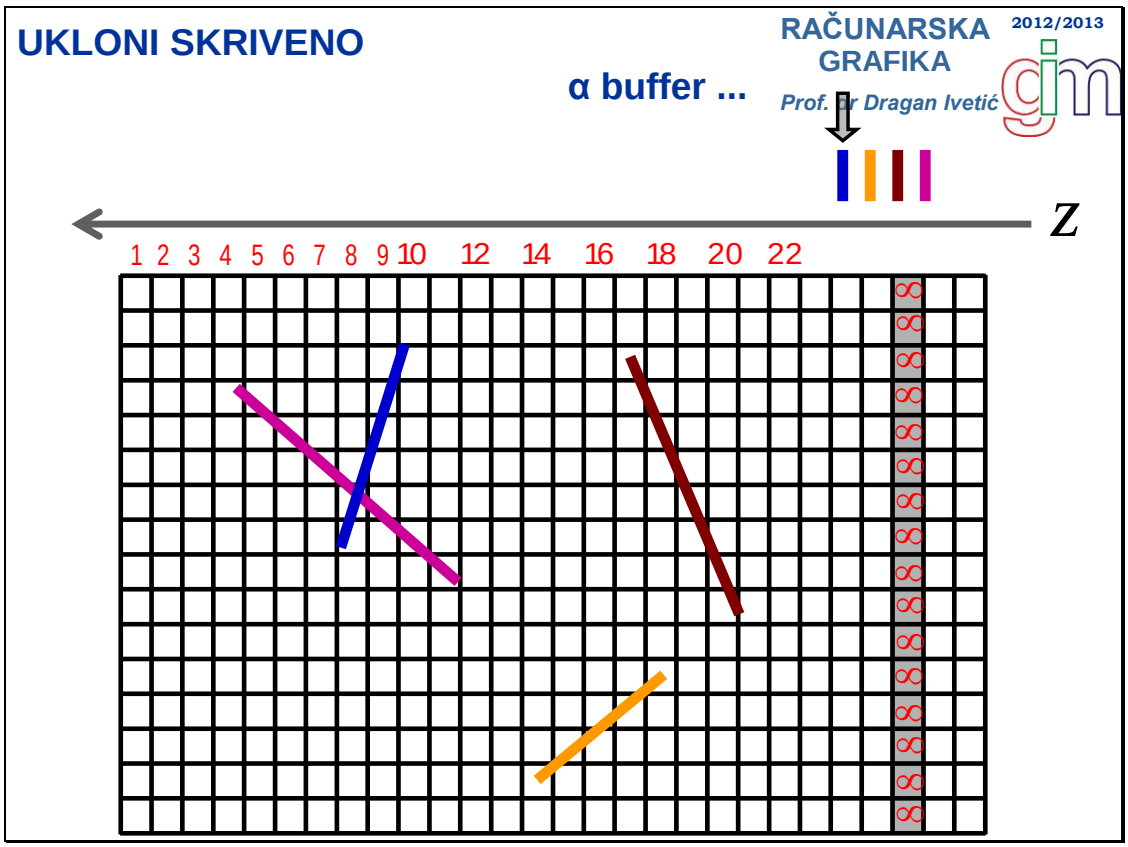
Prof. dr Dragan Ivetić

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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RAČUNARSKA GRAFIKA
2012/2013
Prof. dr Dragan Ivetić
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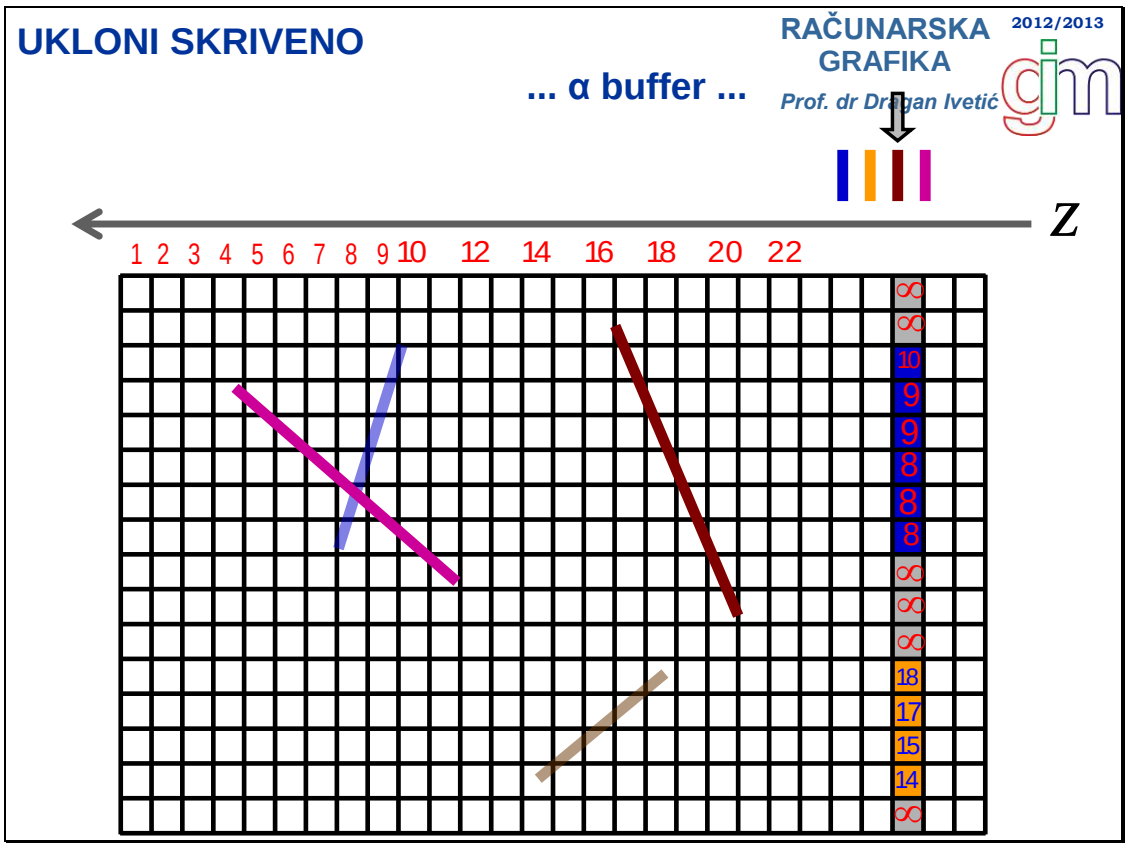
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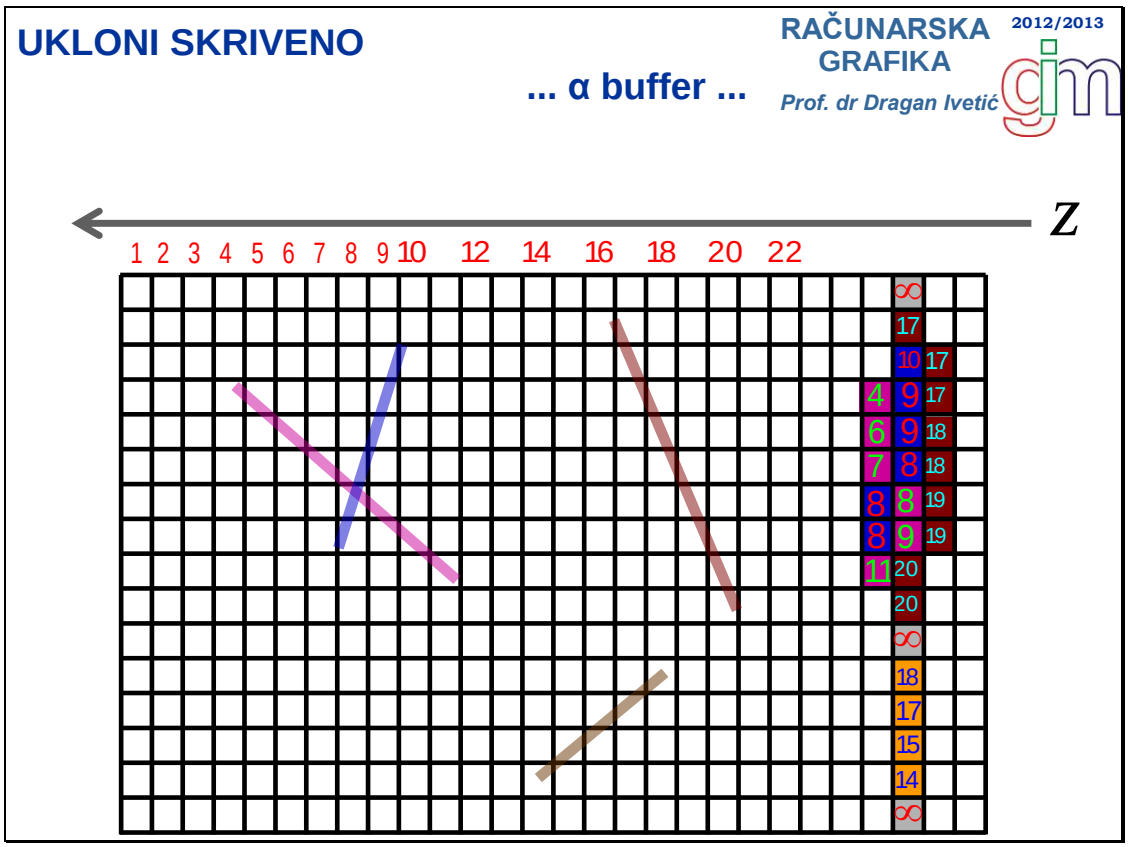
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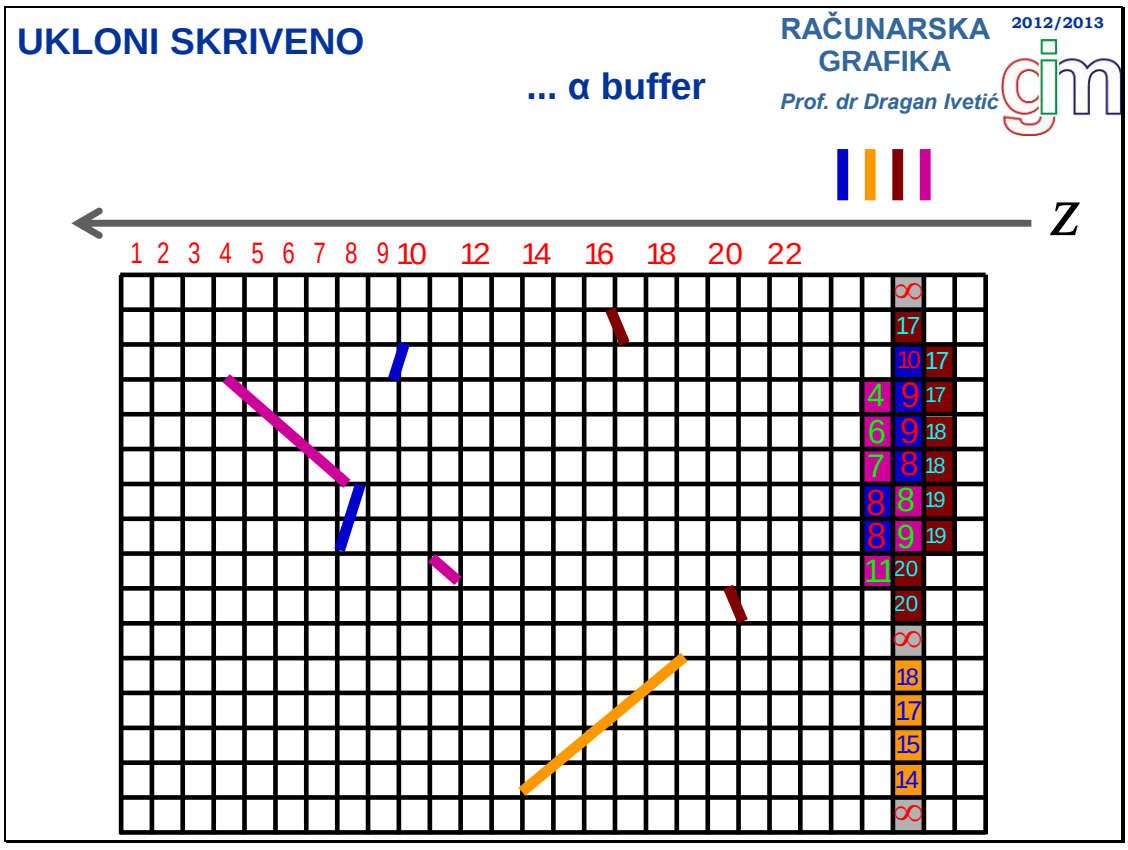
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TEORIJA BOJA

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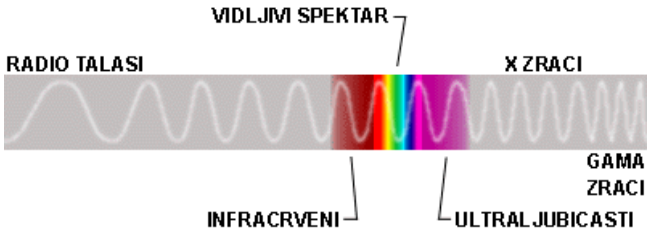
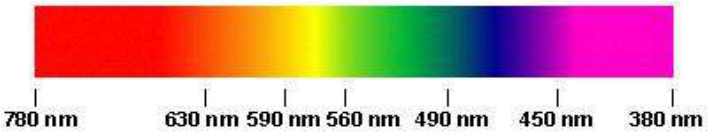
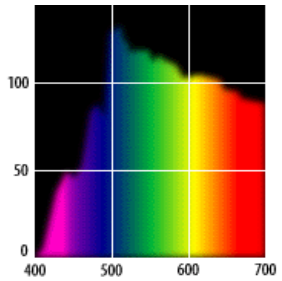
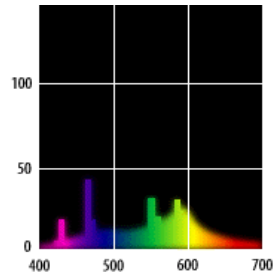
- elektromagnetni talasi - fotoni,
- talasna dužina se percepira kao boja,
- energija je obrnuto srazmerna talasnoj dužini,









700nm 546.1nm 425.8nm

TEORIJA BOJA
Klase medija i modela boja

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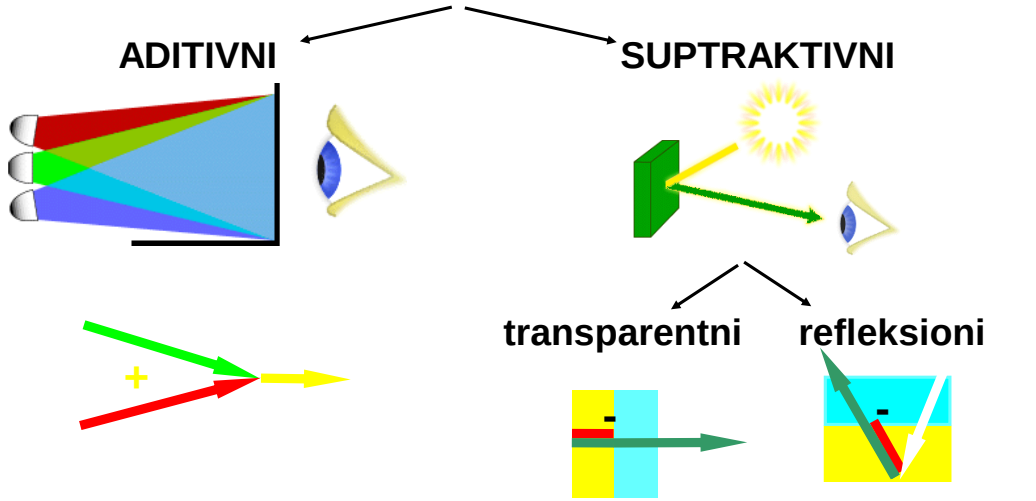

RGB **MODELI BOJA** CMY/CMYK HLS/HSV/HSB LAB

TEORIJA BOJA

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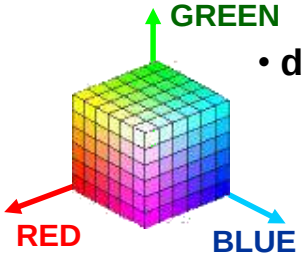
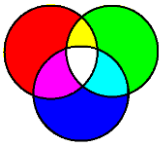
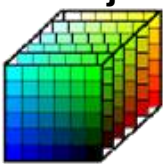
RGB model

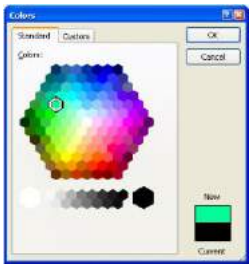


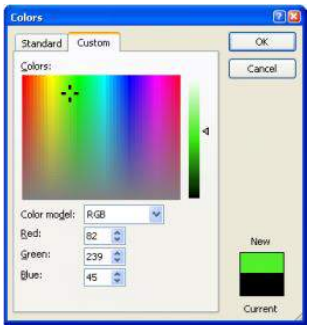
- definisan prostor po RGB bojama,
  - RGB (0,0,0) je koord. početak - crno
  - RGB (1,0,0) - zasićena (puna) crvena
  - RGB (0,1,0) - zasićena zelena
  - RGB (0,0,1) - zasićena plava
  - RGB (1,1,1) - bela
  - od (0,0,0)-(1,1,1) su nijanse sivog



- RGB kocka za prikaz mešanja boja,
- ravni RGB kocke za 2D selektovanje boje.







TEORIJA BOJA

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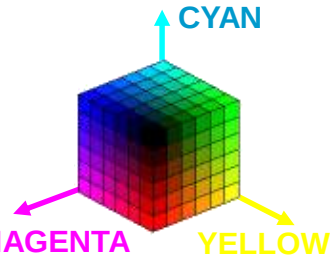
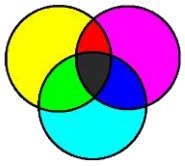
CMY/CMYK model

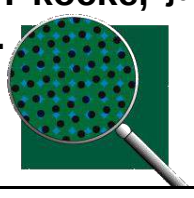
- za suptraktivni medij,
- slaganje filtera (RGB?),
- filtri propuštaju i dijagonalnu boju,
- nema čistih (zasićenih) boja,
- bleda slika (bolesna).

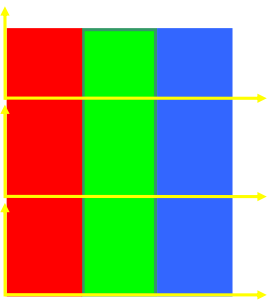




CMY 2 CMYK model

- dodata crna (blacK),
- tj. filter/zaslon za svetlost,
- popravili "istopljenost" CMY kocke,
- i dalje nema zasićenih boja.





TEORIJA BOJA

HLS/HSV/HSB model ...

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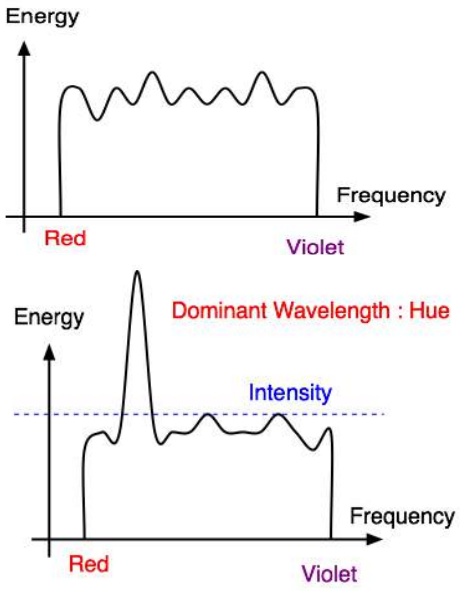
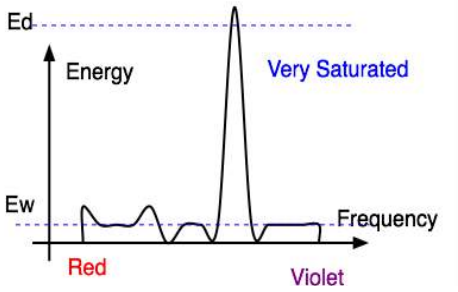
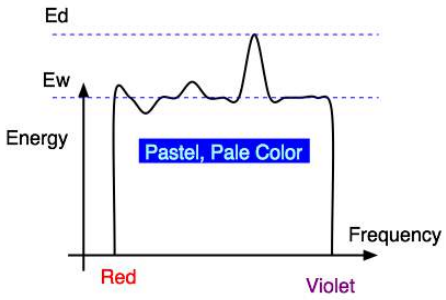
HLS (Hue Luminousity Saturation), HSV (Value), HSB (Brightness)







TEORIJA BOJA

... HLS/HSV/HSB model

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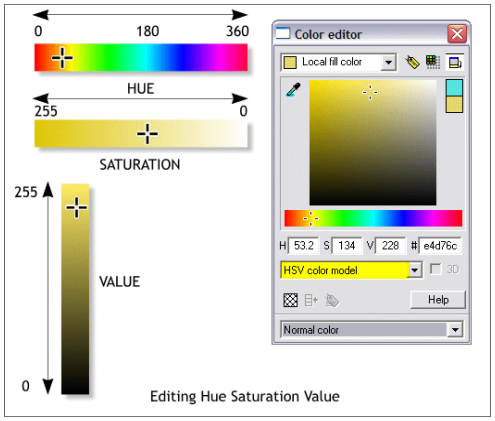
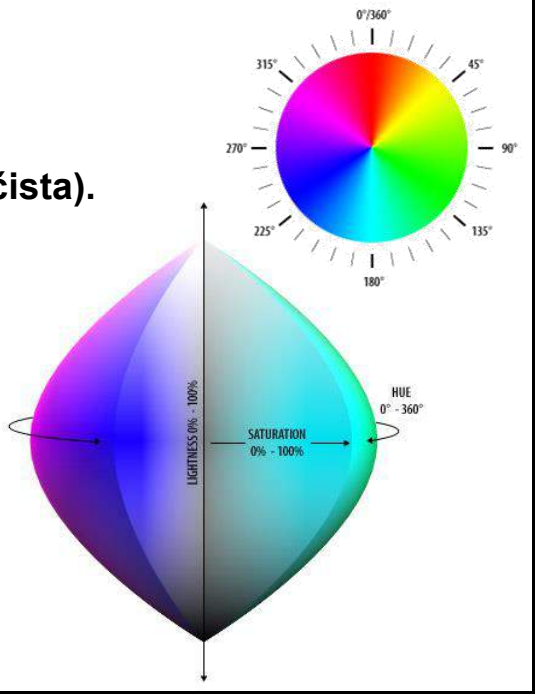
Prati čovekov mentalni model,
izabere boju,
koliko ona treba biti svetla,
koliko zasićena (puno sivog - čista).





TEORIJA BOJA

LAB ...

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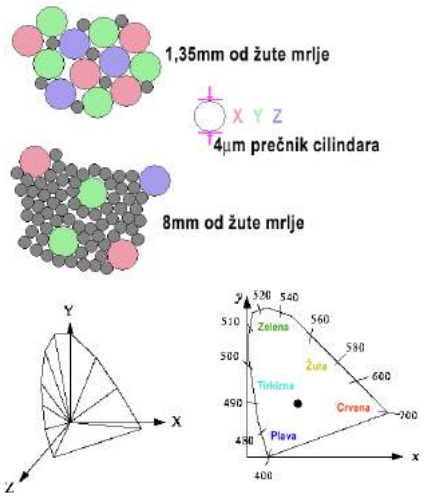
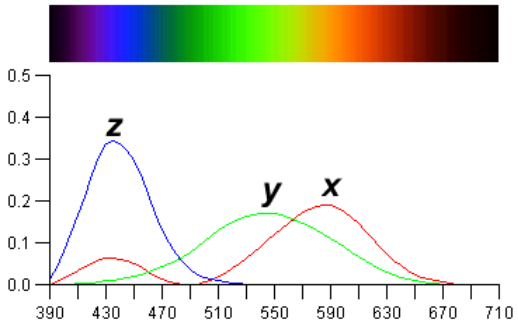
- **1931. godine CIE (Commission Internationale de L'Eclairage), Internacionalna komisija o iluminaciji ustanovila model koji je omogućio predstavljanje punih boja**





TEORIJA BOJA

... LAB ...

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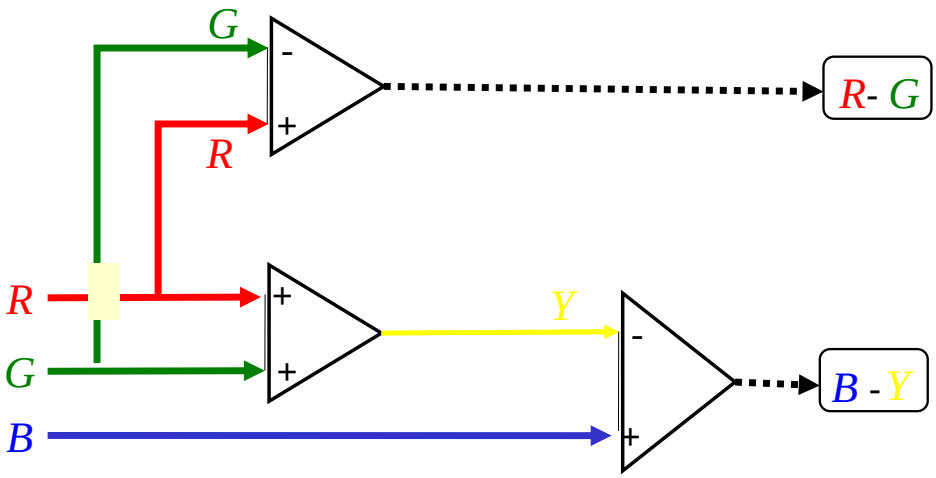
- **1976. godine razvijen CIA LAB po otkriću da se prenose razlike crno/belo (L* dimenzija), crveno/zeleno (a*) i žuto/plavo (b*).**



TEORIJA BOJA

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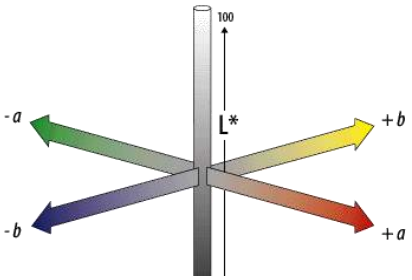
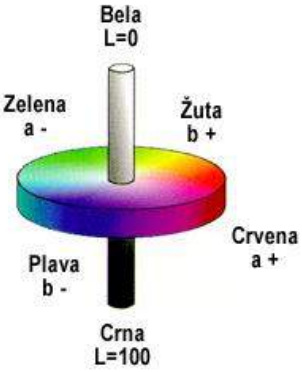
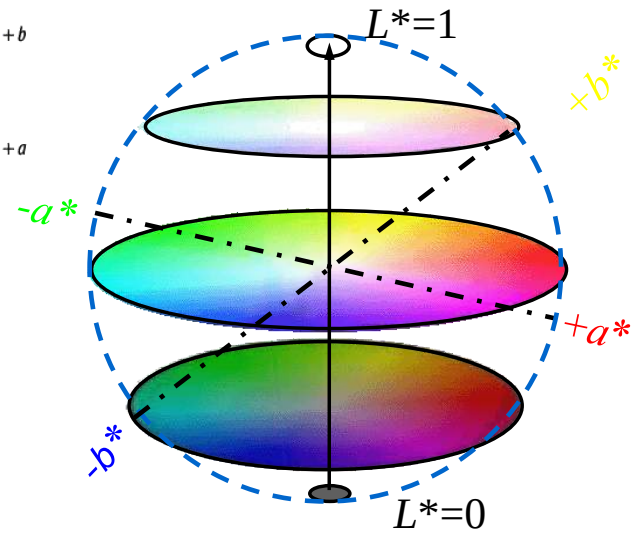
... LAB







TEORIJA BOJA

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Dithering ...

- **da li je neophodno manipulisati celom paletom neke slike, ili možemo malo da uštedimo?** **JUKSTAPOZICIONIRANJE**

Original full-color photograph

Dithered to 256 colors

TEORIJA BOJA

... Dithering ...

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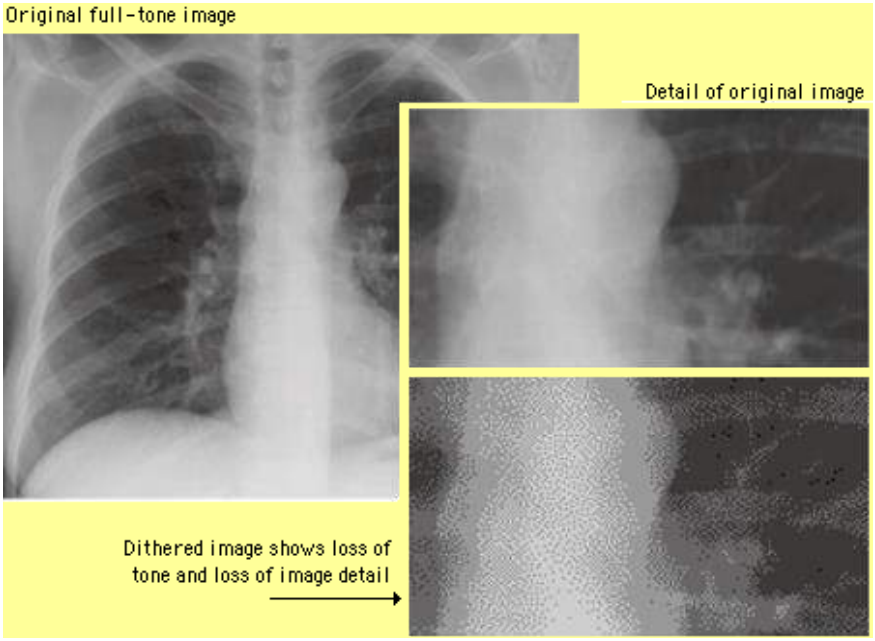
- nije uvek poželjno!



TEORIJA BOJA

... Dithering ...

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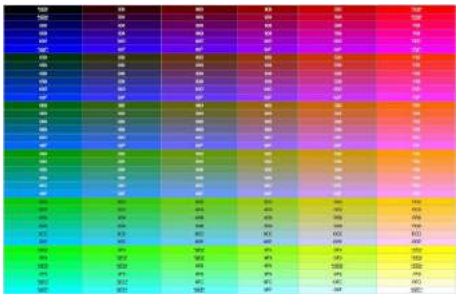
- WEB-safe color palette,
- RGB model boja gde svaka dimenzija ima 256 nivoa

#ffffff #ff0000 #00ff00 #0000ff #ffff00 #000000

- što bi bila paleta od 16.777.216 boja indeksirana sa 3 bajta,
- inženjerski - varamo posmatrača jukstapozicioniranjem boja iz palete od 216 boja (0,0129 ‰ originalne RGB palete),

Za svaku RGB boju usvojeno 6 nivoa (6 x 6 x 6)			
Frakcija	Ključ	Heks	Decimal
0,0	0	00	0
0,2	3	33	51
0,4	6	66	102
0,6	9	99	153
0,8	C	CC	204
1,0	F	FF	255



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... Dithering ...

TEORIJA BOJA

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... Dithering ...

Original PNG, 500 x 375, 872K.

GIF Web 216, koristi 69 boja, 71.2K

GIF WebSnap 256, koristi sve boje, 76.7K.

GIF WebSnap 128, koristi sve boje, 65.8K

Faktori koji utiču na to kako se boje perceptuju?

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Izvor svetla
- pozicija,
- dolazni pravac,
- tip,
- boja izvora.

ILUMINACIJA

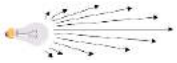
Objekat
- refleksija.

REFLEKSIJA

Posmatrač
- pozicija.

point ligth
- isotropic,
- lako sračun.,
- oštra senka.

spotligth
- anisotropic,
- lako sračun.,
- oštra senka.



ambient ligth
- faraway,
- teško sračun
- meka senka.

Ilumination v.s. shading

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- Isto?
- sračunavamo interakciju svetla sa objektom na osnovu iluminacionog modela (illumination/reflection/ligthing model)
- u obzir uzimamo broj i tip izvora svetlosti, kao i karakteristike materijala,
- ali sve mora da bude veoma brzo pa stoga:
  - koriste samo lokalne informacije po temenu/fragmentu:
    - boja, pravac i udaljenost izvora,
    - boja (materijala) objekta i normala površine,
    - pravac posmatrača,
  - ne rukuje se međurefleksijom objekata i zaklonjenim izvorima.
- sada samo lokalna iluminacija.

Tipovi refleksije svetla

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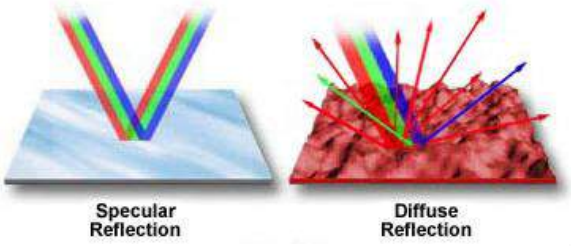

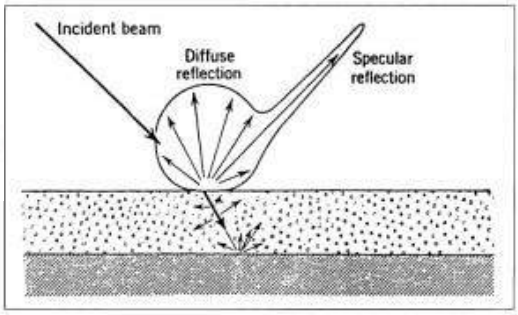

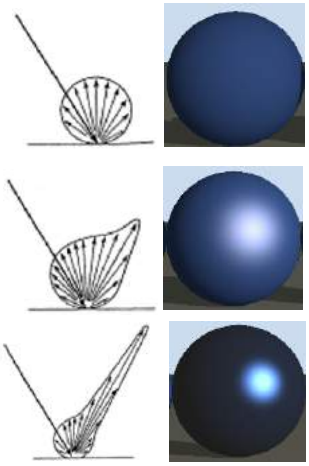

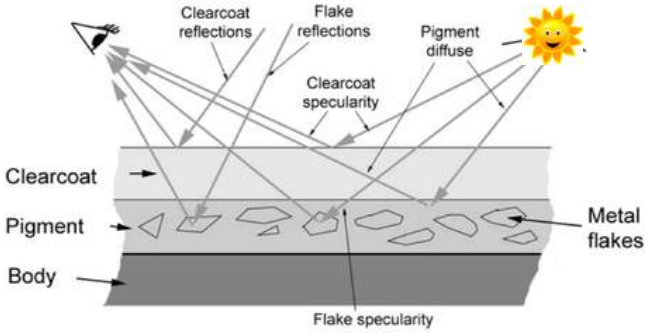

Ideja Phong-ovog iluminacionog modela

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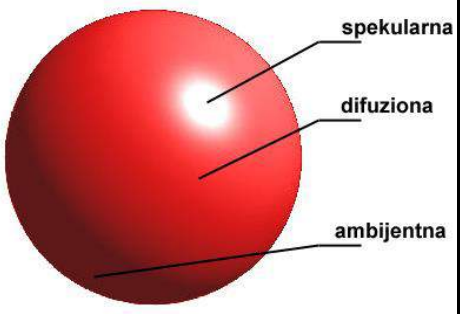
Ideja za određivanje $I_{\text{tačke}}$

- **ambijentno svetlo je uvek prisutno - ambijentna refleksija,**
- **može biti i tačkasti izvor**
  - **difuzna refleksija,**
  - **spekularna refleksija!**

$$I_{\text{tačke}} = I_{\text{r. amb. sv.}} + I_{\text{r. tač. sv.}}$$

$$I_{\text{tačke}} = I_{\text{r. amb. sv.}} + I_{\text{difuz. refl.}} + I_{\text{spek. refl.}}$$

$$I_{\text{tačke}} = I_{\text{r. amb. sv.}} + \Sigma_i I_{\text{r. tač. sv.}}$$



$$I_{\text{tačke}} = I_{\text{r. amb. sv.}} + \Sigma_i I_{\text{r. tač. sv.}}$$

$$I_{\text{tačke}} = I_{\text{r. amb. sv.}} + \Sigma_i I_{\text{r. tač. sv.}}$$

$$I_{\text{tačke}} = I_{\text{r. amb. sv.}} + \Sigma_i I_{\text{r. tač. sv.}}$$

Refleksija ambijentne svetlosti

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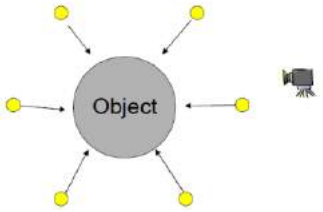
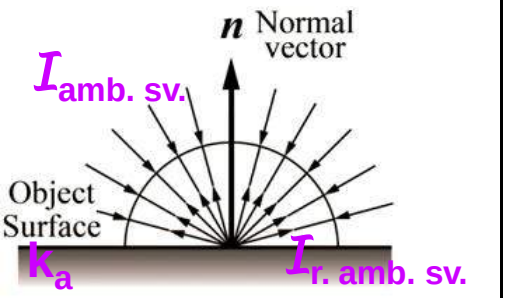


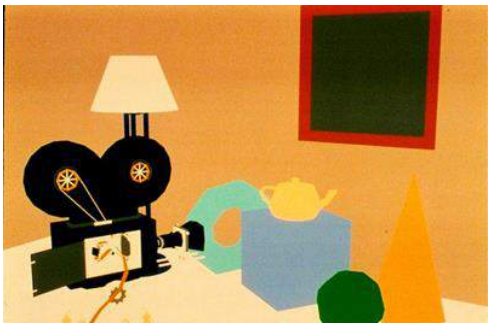


$I_{r.\,amb.\,sv.} = k_a\, I_{amb.\,sv.}$

$I_{r.\,amb.\,sv.R} = O_{dR}\, k_a\, I_{amb.\,sv.R}$

$I_{r.\,amb.\,sv.G} = O_{dG}\, k_a\, I_{amb.\,sv.G}$

$I_{r.\,amb.\,sv.B} = O_{dB}\, k_a\, I_{amb.\,sv.B}$



Difuziona refleksija ...

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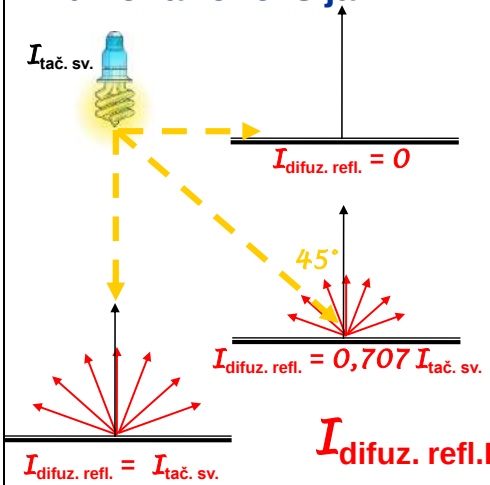
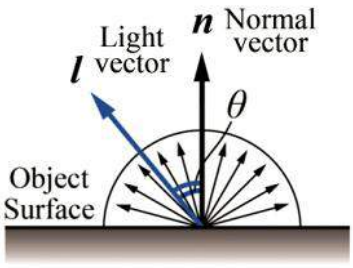


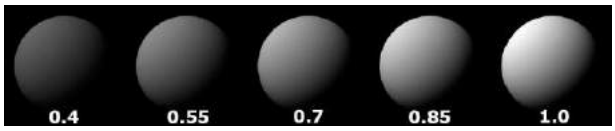


$I_{difuz.\,refl.} = k_d\, I_{tač.\,sv.} \cos(\theta)$

$I_{difuz.\,refl.R} = O_{dR}\, k_d\, I_{tač.\,sv.R} \cos(\theta)$

$I_{difuz.\,refl.G} = O_{dG}\, k_d\, I_{tač.\,sv.G} \cos(\theta)$

$I_{difuz.\,refl.B} = O_{dB}\, k_d\, I_{tač.\,sv.B} \cos(\theta)$



Primer ambijentne i difuzione refleksije

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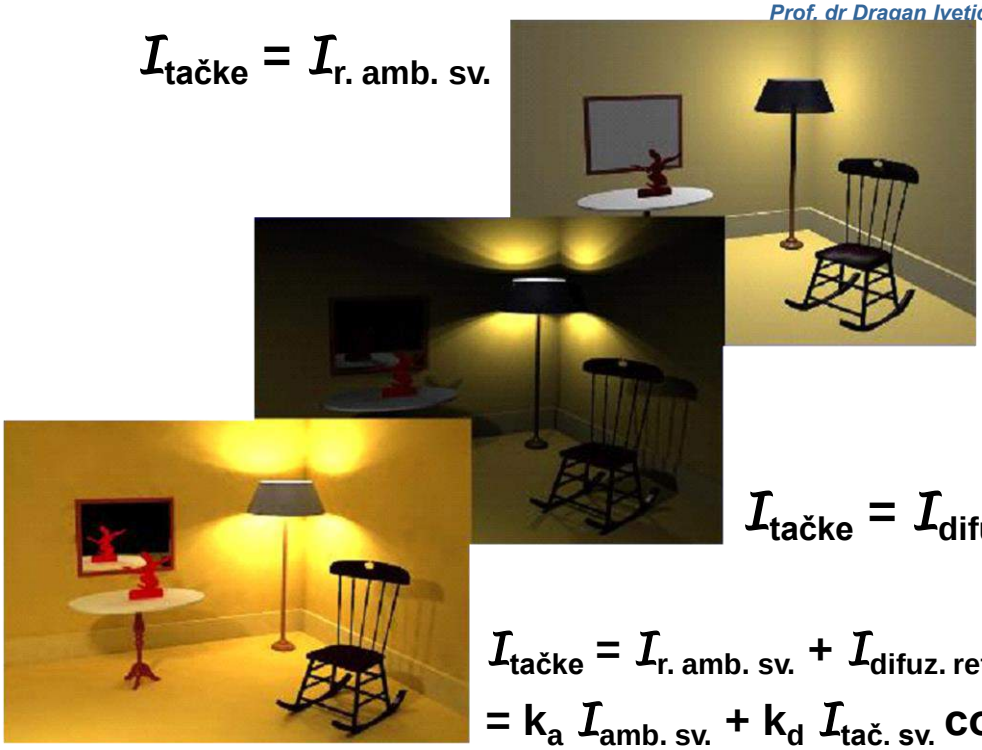
$I_{tačke} = I_{r.\ amb.\ sv.}$



$I_{tačke} = I_{difuz.\ refl.}$

$I_{tačke} = I_{r.\ amb.\ sv.} + I_{difuz.\ refl.} =$

$= k_a\ I_{amb.\ sv.} + k_d\ I_{tač.\ sv.} \cos(\theta)$

Spekularna refleksija

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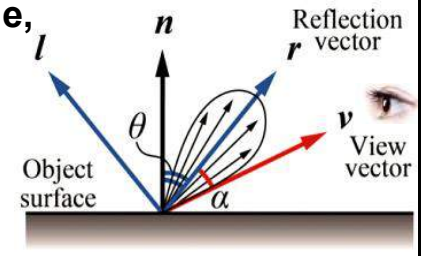
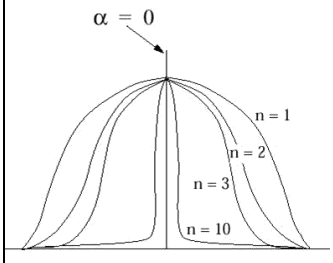
- usmerena refleksija sa sjajne površine,
- kada će intenzitet refleksije biti najveći?
  - za što veće α, ili α = 0?
- po kojoj funkciji?





$I_{spek.\ refl.} = k_s\ I_{tač.\ sv.} \cos^n(\alpha)$

$I_{spek.\ refl.R} = O_{sR}\ k_s\ I_{tač.\ sv.R} \cos^n(\alpha)$

$I_{spek.\ refl.G} = O_{sG}\ k_s\ I_{tač.\ sv.G} \cos^n(\alpha)$

$I_{spek.\ refl.B} = O_{sB}\ k_s\ I_{tač.\ sv.B} \cos^n(\alpha)$

Primeri spekularne reflekcije

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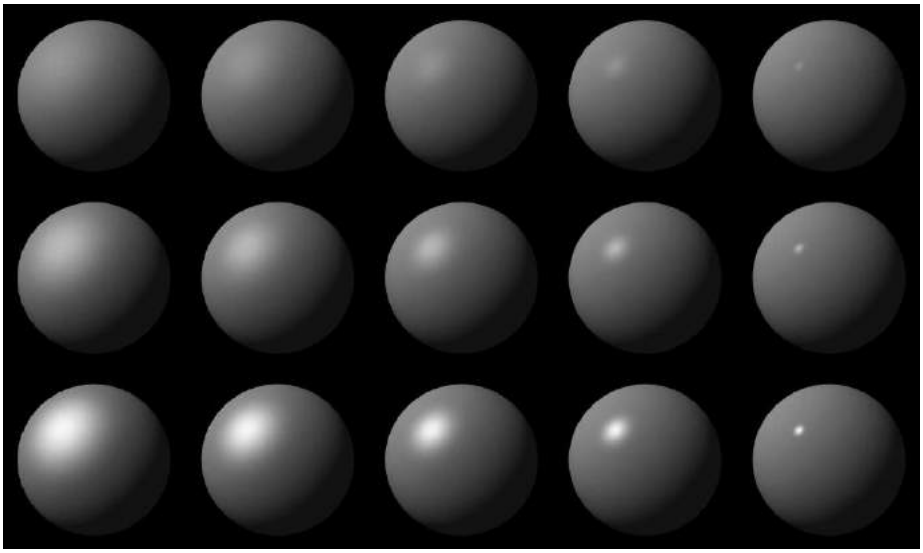
n 3.0 5.0 10.0 27.0 200.0



$k_s = 0.1$,

$k_s = 0.25$,

$k_s = 0.5$,

Slabljenje reflektovane svetlosti

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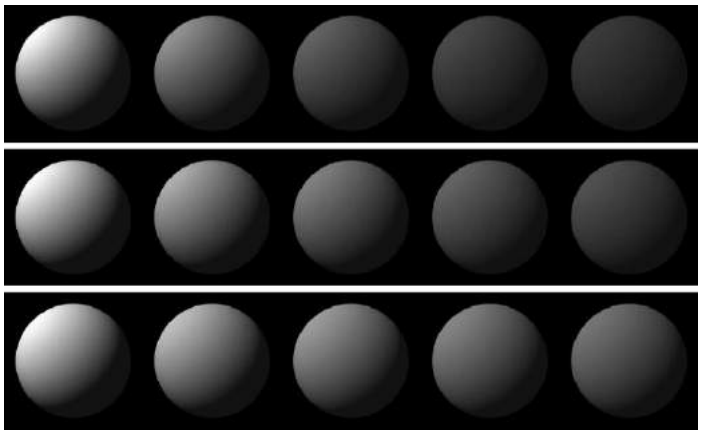
$f_{slabi} = 1 / d^2$

$$f_{slabi} = \min\left(\frac{1}{c_1 + c_2 d + c_3 d^2}, 1\right)$$

d 1.0 1.375 1.75 2.125 2.5



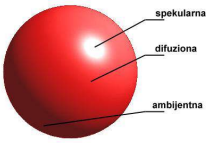
$c_1 = c_2 = 0.0$, $c_3 = 1.0$,

$c_1 = c_2 = 0.25$, $c_3 = 0.5$,

$c_1 = c_3 = 0.0$, $c_2 = 1.0$,

Na koji tip refleksije (A, D, S) treba primeniti slabljenje? Zašto?

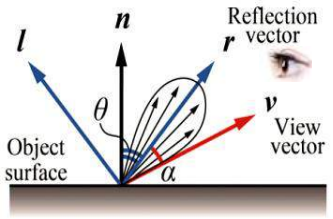
Phong-ov iluminacioni model



$$I_{tačke} = k_a\, I_{amb.\,sv.} + f_{slabi} \sum I_{tač.\,sv.} \,[k_d \cos(\theta) + k_s \cos^n(\alpha)]$$

$$I_{tačke\lambda} = O_{d\lambda}\, k_a\, I_{amb.\,sv.\lambda} + f_{slabi} \sum I_{tač.\,sv.\lambda} \,[O_{d\lambda}\, k_d \cos(\theta) + O_{s\lambda}\, k_s \cos^n(\alpha)]$$

a da se ne računaju ugovi θ i α



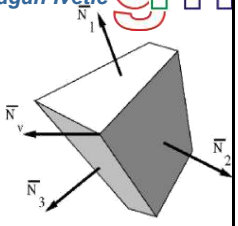
$$I_{tačke\lambda} = O_{d\lambda}\, k_a\, I_{amb.\,sv.\lambda} + f_{slabi} \sum I_{tač.\,sv.\lambda} \,[O_{d\lambda}\, k_d\, (\bar{n}\cdot\bar{l}) + O_{s\lambda}\, k_s\, (\bar{v}\cdot\bar{r})^n]$$

Senčenje ...

- treba da obojimo površinu bojom,
- kako da odredimo boju?
- kako da obojimo?
- imamo samo normale po temenima...

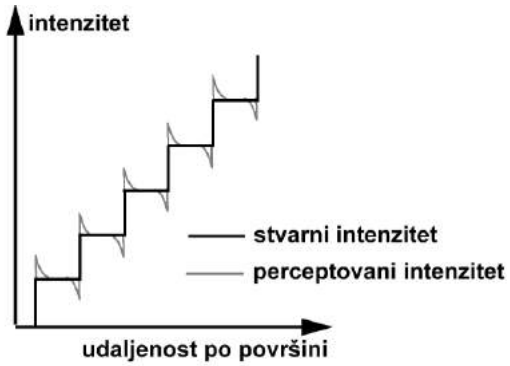
- zavisno od modela senčenja:
  - konstantno senčenje,
    - $I_{tačke}$ ide jednom po poligonu,
    - skroman hardver,
  - Gouraud senčenje,
    - $I_{tačke}$ ide koliko ima temena po poligonu,
    - šta je sa normalom za dato $I_{tačke}$?
  - Phong senčenje,
    - $I_{tačke}$ ide više od broja temena poligona, koliko max?
    - zahtevan hardver.

... Senčenje ... konstantno ...

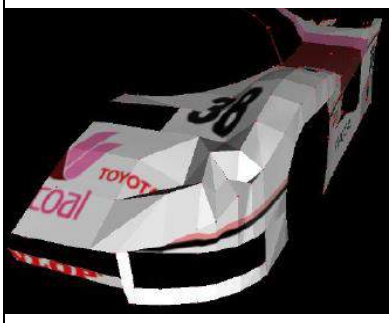


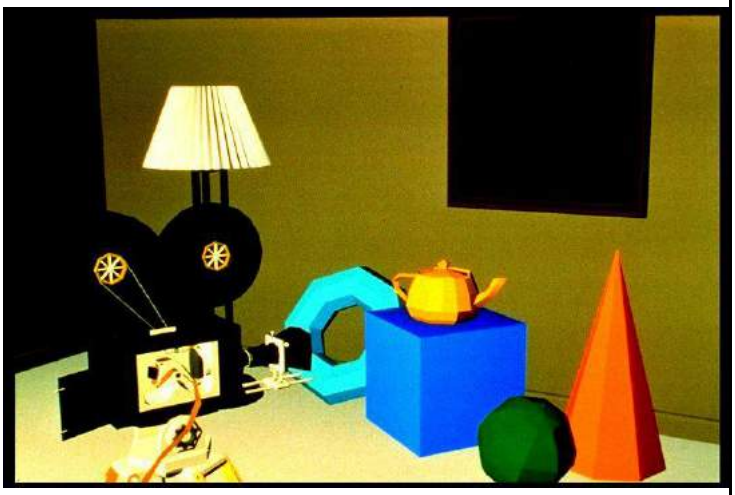
Pretpostavke:

- **izvor svetla i gledalac su jako (∞) udaljeni,**
- **jedna iluminaciona vrednost $I_{\text{tačke}}$ po poligonu,**
- **OK ako poligon koji se senči nije aproksimacija površine,**
  - **suprotno, biće veoma naglašena nepovezanost poligona.**



... Senčenje ... ... konstantno





... Senčenje ...

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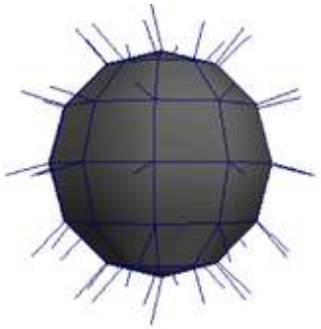
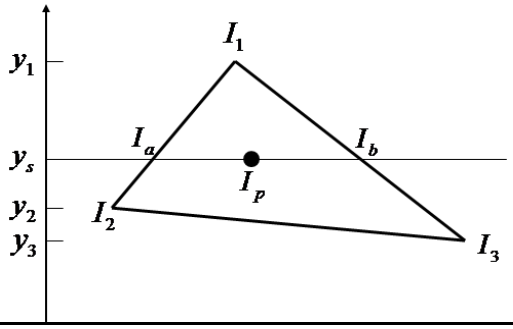
Gouraud ...

- **kako da eliminiše prelaze sa jednog na drugi poligon?**

$$\overline{N}_V = \frac{\sum_{1 \le i \le n} \overline{N}_i}{\left| \sum_{1 \le i \le n} \overline{N}_i \right|}$$



- **pa računa $I_{\text{tačke}}$ po temenima poligona,**
- **pa ih interpolira po ostatku poligona.**



$$I_a = I_1 \frac{y_s - y_2}{y_1 - y_2} + I_2 \frac{y_1 - y_s}{y_1 - y_2}$$

$$I_b = I_1 \frac{y_s - y_3}{y_1 - y_3} + I_3 \frac{y_1 - y_s}{y_1 - y_3}$$

$$I_p = I_a \frac{x_b - x_p}{x_b - x_a} + I_b \frac{x_p - x_a}{x_b - x_a}$$

... Senčenje ...

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... Gouraud ...

... Senčenje ...

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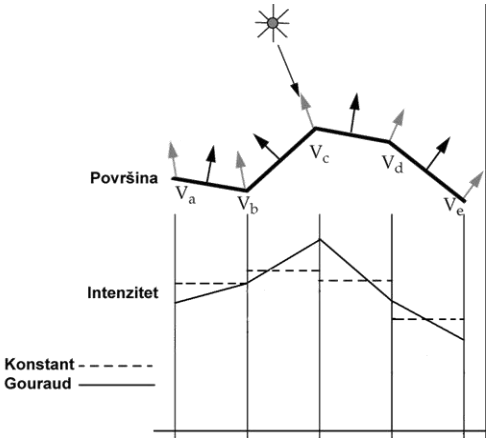
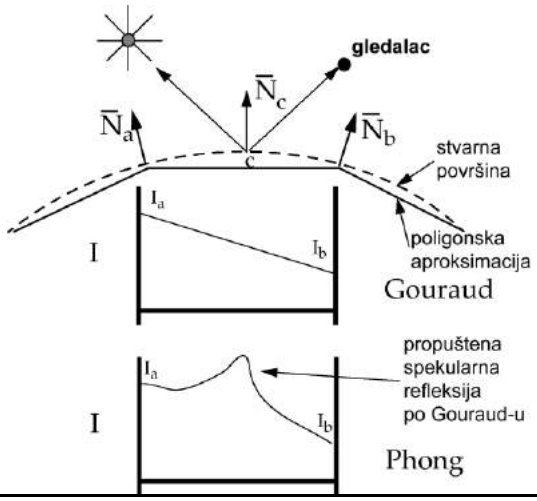
... Gouraud

v.s. konstantno



- **koncentracija na usrednjene normale i interpolacija ilminacije unutar poligona,**
- **veliki nedostatak, koji?**



... Senčenje ...

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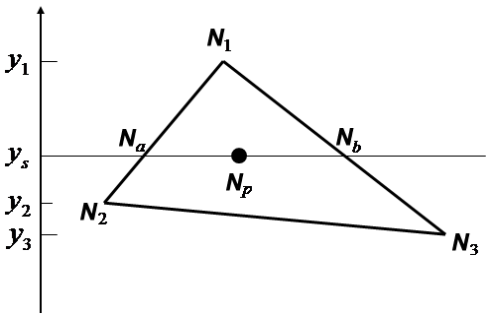
Phong ...

- **kako da korektno senči kada ima i spekularne refleksije?**
- **što kasnije da računa $I_{\text{tačke}}$, unutar poligona.**



$$N_a = N_1 \frac{y_s - y_2}{y_1 - y_2} + N_2 \frac{y_1 - y_s}{y_1 - y_2}$$

$$N_b = N_1 \frac{y_s - y_3}{y_1 - y_3} + N_3 \frac{y_1 - y_s}{y_1 - y_3}$$

$$\tilde{N}_p = \frac{N_a}{\|N_a\|}\left[\frac{x_b - x_p}{x_b - x_a}\right] + \frac{N_b}{\|N_b\|}\left[\frac{x_p - x_a}{x_b - x_a}\right]$$

- **kada odredi N_p tada računa i $I_{\text{tačke}}$ u p.**
- **koliko puta se sada sračunava iluminacija?**

... Senčenje ...

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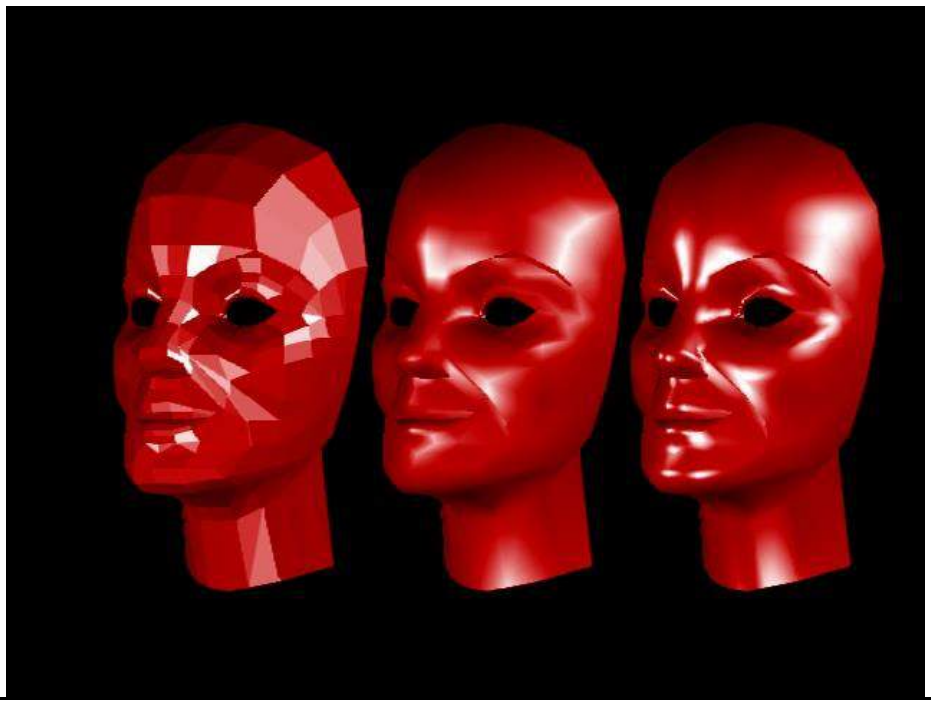

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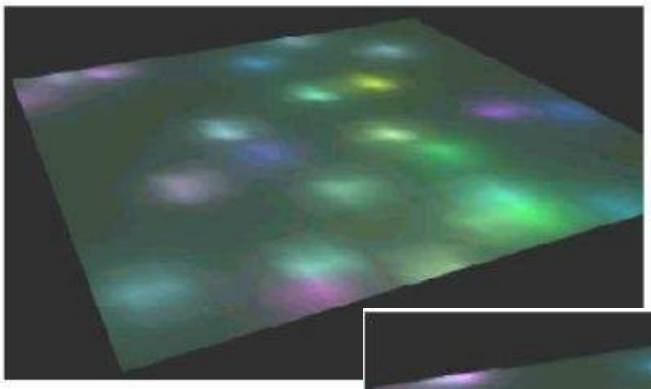
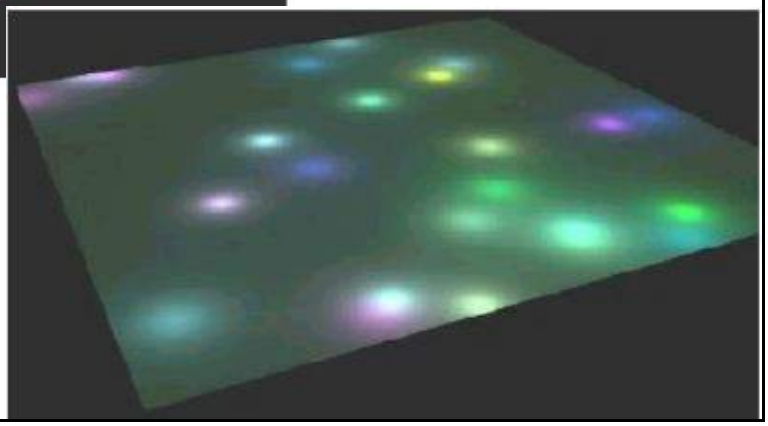


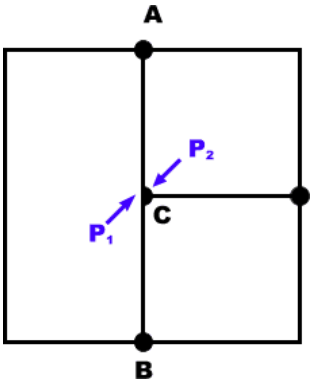
Gouraud senčenje disko poda, problem i kada je mali broj poligona...



Phong senčenje

... Senčenje ...
problemi sa interpolacijama ...

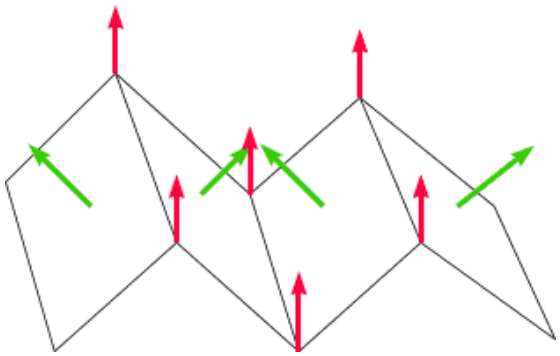
- problem sa sračunavanjem normala u temenima,



  - A i B temena dele svi poligoni, a C teme dele samo oni s desne strane,
  - P_1 sračunat na osnovu (A, B), a P_2 biće baš C, odnosno u okolini kao (A,C) i (C,B),
  - značajan diskontinuitet u senčenju.
- rešenja:
  - podeli sve na trouglove,
  - uključi fantomsko teme C za P_1.

... Senčenje ...
... problemi sa interpolacijama ...

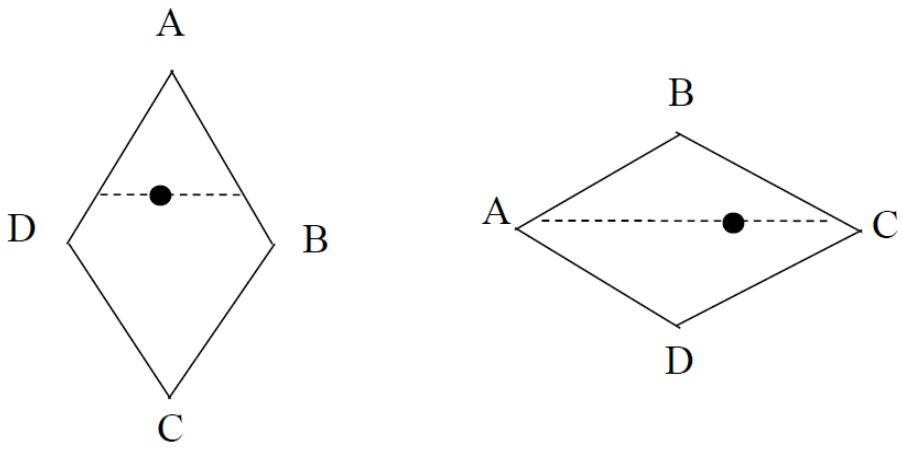
- problem sa sračunavanjem normala u temenima,
- normale površina su usrednjene u zajedničkim temenima,
- kako će izgledati ove površine kada se osenče?



- rešenje?

... Senčenje ...
... problemi sa interpolacijama

- **interpolacija iluminacije nije invarijantna za rotaciju površine sa barem 4 temena?**



- **rešenje?**

... Senčenje