# 9. Obične diferencijalne jednačine, problem početne vrednosti

## 1. Drugi Njutnov zakon

**Zadatak 1**

Ako na telo mase , koje je u trenutku imalo položaj i brzinu , deluje konstantna sila od , naći položaj tela svake sekunde tokom narednih .

Naći numeričko rešenje Ojlerovim metodom i metodom RK4 u 10 tačaka, zadajući korak h. Na istom grafiku nacrtati i uporediti 2 numerička i analitičko rešenje ().

Uporediti nalaženje numeričkih rešenja u 10, 100, 1000, 10000 tačaka, menjajući korak h.

Rešenje (za 10 tačaka):

sTTrue =

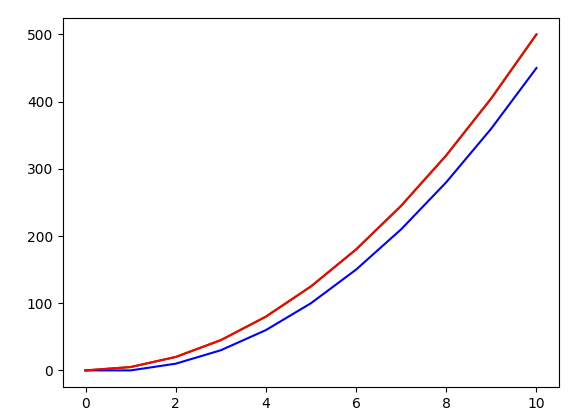
0 5 20 45 80 125 180 245 320 405 500

sTEuler =

0 0 10 30 60 100 150 210 280 360 450

sTRK4 =

0 5 20 45 80 125 180 245 320 405 500



Ojlerova metoda greši za veliki korak h (tj. za mali broj tačaka)!

## 2. Diskretne jednačine

**Zadatak 2**

Pri dodavanju gasa vozlio ubrzava . Pri kočenju vozlio usporava . Ako se vozilo iz stanja mirovanja kretalo po deonici puta dužine sa ograničenjem brzine , a zatim ostatak puta sa ograničenjem brzine od i ako je napravilo pauzu između 5. i 10. min., koliki put je prešlo nakon 20min?

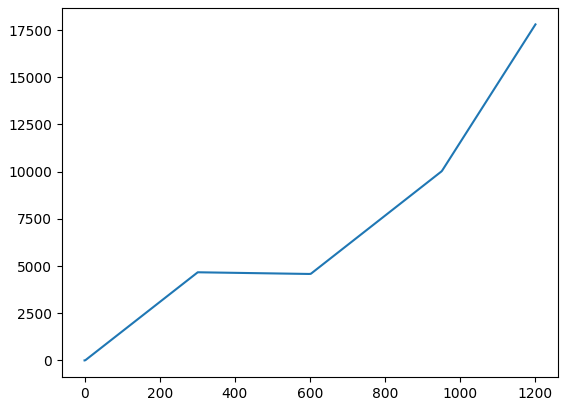
1. Formulisati diferencijalnu jednačinu u posebnoj MATLAB datoteci (uz pomoć if selekcije definisati diskretne uslove kretanja):

![Graphical user interface, text, application, email

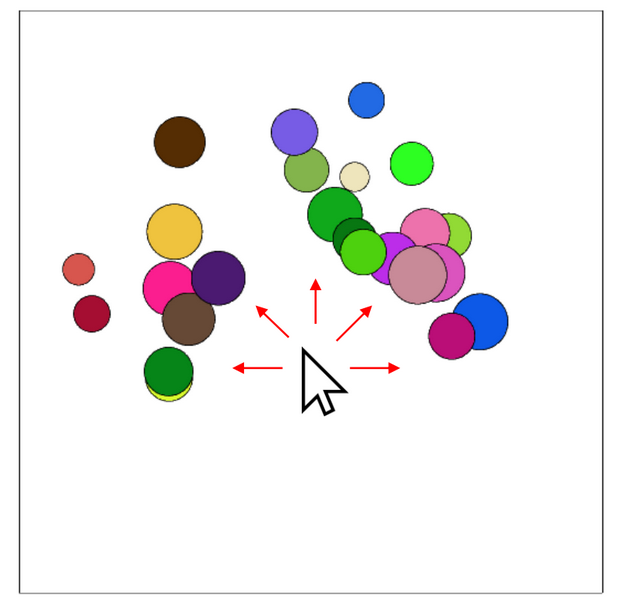
Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAkACQAAD/4RDiRXhpZgAATU0AKgAAAAgABAE7AAIAAAAIAAAISodpAAQAAAABAAAIUpydAAEAAAAQAAAQyuocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEFuZGplbGEAAAWQAwACAAAAFAAAEKCQBAACAAAAFAAAELSSkQACAAAAAzU2AACSkgACAAAAAzU2AADqHAAHAAAIDAAACJQAAAAAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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1. Rešiti PPV

rešenje:



## 3. Fizika u video igrama (interaktivno kretanje)



Slika 1. Interaktivno kretanje

Poznavajući fizičke karakteristike objekata i početne uslove kretanja, potrebno je simulirati njihovo kretanje u proizvoljnom vremenskom intervalu, pri čemu uslovi kretanja mogu da se menjaju u svakom vremenskom trenutku (slika 1). Radi jednostavnosti primera odabrane su sfere.

Jednačina položaja takvog kretanja (2. Njutnov zakon) je:

|  |  |
| --- | --- |
|  | (1) |

, gde su trenutni položaj tela, je masa tela, je sila koja deluje na telo, a proteklo vreme. je veličina koja menja uslove kretanja u svakom vremenskom trenutku. je nepoznata funkcija i zavisi od korisničke interakcije. Nije moguće izraziti ovu funkciju analitički.

Funkciju položaja je međutim u svakom vremenskom trenutku moguće razviti u Tejlorov red:

Ograničavanjem beskonačne sume Tejlorovog reda na konačnu, moguće je numeričkim putem doći do rešenja diferencijalne jednačine u uzastopnim vremenskim trenucima.

Ojlerov metod uzima u obzir prva 2 člana reda:

Diferenciranjem obe strane jednačine dobija se:

Uvođenjem smene , dobija se:

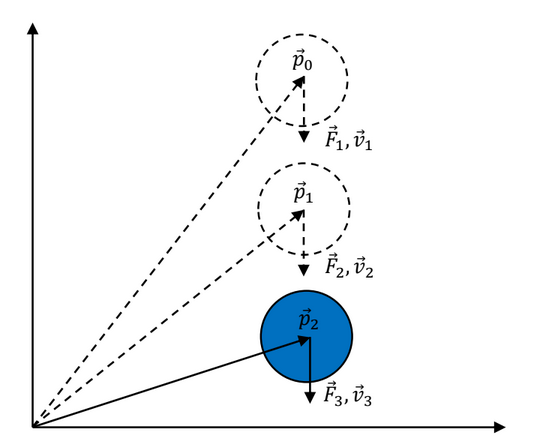
|  |  |
| --- | --- |
|  |  |
|  | (2) |

Zamenom (1) u (2), dobija se:

Prevođenjem u iterativni zapis, dobija se:

Masa tela je konstantna. Ako je silu u svakom trenutku moguće izraziti i izračunati i ako su početni položaj i početna brzina tela poznati, tada je **Ojlerovom integracijom** moguće naći položaj i brzinu u svakom vremenskom trenutku :

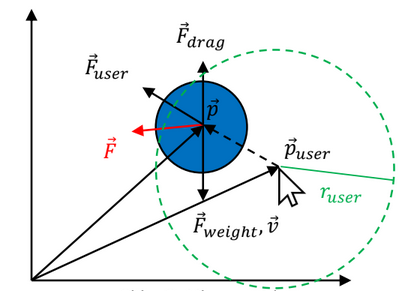
|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

Slika 2. Ojlerova integracija

**RK4 metoda** podrazumeva iste parametre, pa se može upotrebiti na **isti način**.

Ako su poluprečnik i gustina sfere poznati (za gumu npr. ), masa sfere se može izračunati na sledeći način:

Ukupna sila koja deluje na telo u svakom trenutku se može izračunati kao linearna kombinacija različitih komponenata:

Slika 3. Ukupna sila

Težina tela se izračunava na sledeći način:

, gde je masa tela, a je gravitaciono ubrzanje.

Sila otpora vazduha se izračunava na sledeći način:

, gde je gustina vazduha, je brzina tela, je koeficijent aerodinamičnosti tela (za sfere ), a je poprečni presek tela normalan na pravac kretanja (za sfere ). Primetiti da je sila otpora vazduha po pravcu ista, a po smeru suprotna brzini kretanja.

Korisnička sila se izračunava na sledeći način:

, gde je položaj tela, je položaj pokazivača miša, poluprečnik kruga delovanja korisničke sile, a je intenzitet korisničke sile.

**Zadatak 3**

Simulirati slobodan pad gumenih sfera nasumično generisanih položaja iz stanja mirovanja kroz vazduh. Omogućiti da korsinik pokazivačem miša može da unese dodatnu silu u simulaciju.

Konstante prostora:

|  |  |
| --- | --- |
| dimenzije prostora |  |
| gravitaciono ubrzanje |  |
| gustina vazduha |  |
| gustina gume |  |
| koeficijent aerodinamičnosti sfere |  |

Sfere:

|  |  |  |
| --- | --- | --- |
| veličina | min. nasumično generisana vrednost | maks. nasumično generisana vrednost |
| broj | 25 | 25 |
| poluprečnik |  |  |
| početne brzine sfera |  |  |
| položaji sfera |  |  |

Korisnička sila:

|  |  |
| --- | --- |
| poluprečnik kruga delovanja korisničke sile |  |
| intenzitet korisničke sile |  |

1. Definisati konstante prostora:

worldSize = [10.0, 10.0] # [m]; dimenzije prostora

g = 9.81 # [m/s^2]; gravitaciono ubrzanje

air\_density = 1.225 # [kg/m^3]; gustina vazduha

rubber\_density = 1522 # [kg/m^3]; gustina gume

drag\_coefficient = 0.47 # koeficijent aerodinamičnosti sfera

1. Definisati sfere:

# sfere

sphere\_count = 25

r = (0.5 + np.random(sphere\_count)\*0.5)\*0.5 # [m]; dimenzije sfera

A = r\*\*2\*np.pi # [m^2]; poprečni preseci sfera

m = rubber\_density\*4/3\*r\*\*3\*np.pi # [kg]; mase (gumenih) sfera

v = np.zeros((sphere\_count, 2)) # [m/s]; trenutne brzine sfera

# [m]; trenutni polozaji sfera

p = np.random.rand(sphere\_count, 2)\*0.5

p[:, 0] = (0.25 + p[:, 0])\*world\_size[0]

p[:, 1] = (0.75 + p[:, 1])\*world\_size[1]

colors = np.random.rand(sphere\_count, 3) # (R,G,B); boje sfera

1. Inicijalizovati grafički interfejs:

% GUI

fig, ax = plt.subplots() # prozor

plt.axis((0, world\_size[0], 0, world\_size[1])) # ogranicavanje prikaza u okviru dimenzija prostora

ax.set\_aspect('equal') # sprecavanje reskaliranja prikaza

plt.axis('off') # sakrivanje osa

# ivice

plt.plot([0, world\_size[0]], [0, 0], c='k')

plt.plot([0, world\_size[0]], [world\_size[1], world\_size[1]], c='k')

plt.plot([0, 0], [0, world\_size[1]], c='k')

plt.plot([world\_size[0], world\_size[0]], [0, world\_size[1]], c='k')

# sfere

spheres = []

for sphere in range(sphere\_count): # za svaku sferu(sphere)

location = p[sphere, :]

radius = r[sphere]

diameter = 2\*radius

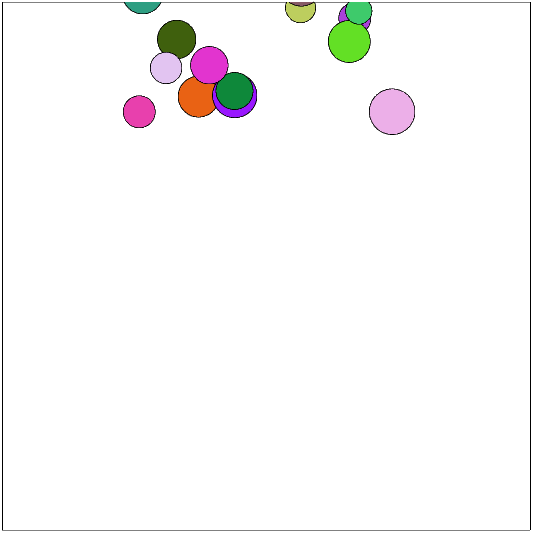
x = location[0] - radius

y = location[1] - radius

color = colors[sphere, :]

spheres.append(plt.Circle((x, y), radius, facecolor=colors[sphere], edgecolor='black'))

Rezultat:



Slika 4. Početak simulacije

1. Simulirati kretanje sfera Ojlerovom integracijom:

fps = 60 # broj osvežavanja prikaza u sekundi

timeScale = 1.0 # brzina simulacije

t1 = 0 # [s]; početni vremenski trenutak

dt = 1/fps # [s]; vremenska razlika između koraka

def init(): # inicijalizacija pocetnih pozicija

for sphere in spheres:

ax.add\_patch(sphere)

return spheres

# funkcija koja se poziva prilikom iscrtavanja svakog frame-a

def animate(f):

t2 = t1 + dt\*time\_scale # naredni vremenski trenutak

# azuriranje polozaja i iscrtavanje

for idx, sphere in enumerate(spheres):

# sile

F = [0, 0]

# integracija

# --------------------------------------------------------------

ddpX = lambda t, p, v: F[0]/m[idx] # p"(t) = F(t)/m) funkcija kretanja (x)

ddpY = lambda t, p, v: F[1]/m[idx] # p"(t) = F(t)/m) funkcija kretanja (y)

\_, pnX = eulerN.eulerN(t1, t2, t2 - t1, np.array([p[idx, 0], v[idx, 0]]), ddpX, 0.0)# integracija(x)

\_, pnY = eulerN.eulerN(t1, t2, t2 - t1, np.array([p[idx, 1], v[idx, 1]]), ddpY, 0.0)# integracija(y)

p[idx, :] = [pnX[0, -1], pnY[0, -1]] # trenutni polozaj

v[idx, :] = [pnX[1, -1], pnY[1, -1]] # trenutna brzina

# prikaz

# --------------------------------------------------------------

location = p[idx, :]

radius = r[idx]

x = location[0] - radius

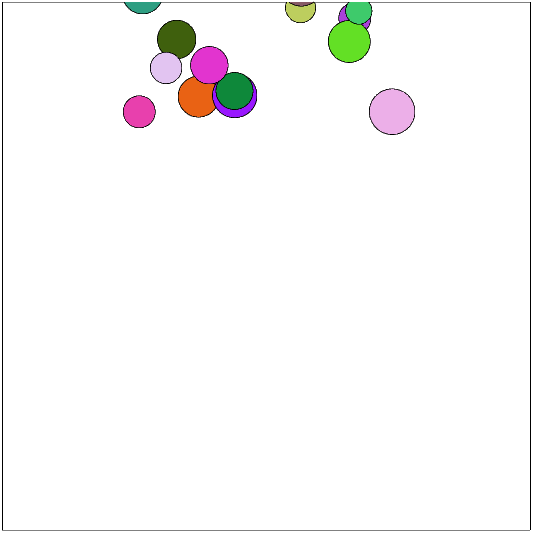
y = location[1] - radius

sphere.center = (x, y)

ax.add\_patch(sphere)

return spheres

Rezultat:



Slika 5. Bez sile kretanje nije moguće

1. Uvesti sile težine tela i otpora vazduha:

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.

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# azuriranje polozaja i iscrtavanje

for idx, sphere in enumerate(spheres):

# sile

# --------------------------------------------------------------

F\_weight = [0, -m[idx]\*g] # tezina tela (x, y)

velocity = v[idx, :]

F\_drag = -velocity\*np.linalg.norm(velocity, 2)\*0.5\*air\_density\*drag\_coefficient\*A[idx] # otpor vazduha (x, y)

F = F\_weight + F\_drag

# integracija

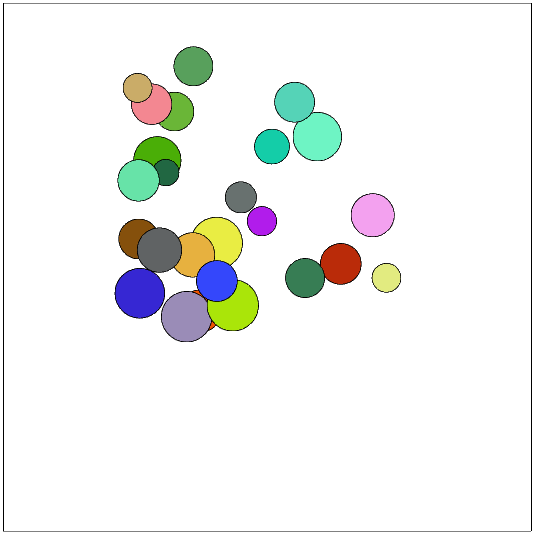
# ----------------------------------------------------------------------

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Rezultat:



Slika 6. Slobodan pad

1. Definisati funkciju normalize(in\_vector) koja za ulazni vektor in\_vector vraća jedinični vektor out istog pravca i smera:

def normalize(in\_vector):

magnitude = np.linalg.norm(in\_vector, 2)

if magnitude == np.inf or magnitude <= 0:

out = [1, 0]

else:

out = in\_vector/magnitude

return out

1. Definisati funkciju gui\_mouse\_move(event) koja na događaj pomeranja pokazivača miša čuva položaj miša u globalnoj promenljivoj mouse\_location:

mouse\_location = [None, None] # inicijalizacija globalne promenljive - pozicija misa

def gui\_mouse\_move(event):

global mouse\_location

mouse\_location = [event.xdata, event.ydata]

1. Pre procedure iz koraka d), definisati parametre korisničke sile i registrovati funkciju gui\_mouse\_move da reaguje na događaj pomeranja pokazivača miša:

# user force

r\_user = min(world\_size) \* 0.2 # [m]

f\_user = 15000 # [N = kg \* m / s^2]

p\_user = [-np.inf, -np.inf]

plt.connect('motion\_notify\_event', gui\_mouse\_move) # registrovanje funkcije

1. Uvesti delovanje korisničke sile:

.

.

.

pUser = mouse\_location # čitanje vrednosti globalne promenljive

# ažuriranje položaja i iscrtavanje

# azuriranje polozaja i iscrtavanje

for idx, sphere in enumerate(spheres):

# sile

# --------------------------------------------------------------

.

.

.

F\_user = [0, 0]

try:

direction = p[idx, :] - p\_user

if np.linalg.norm(direction, 2) <= r\_user:

F\_user = normalize(direction)\*f\_user # korisnicka sila (x, y)

except:

pass

F = F\_weight + F\_drag + F\_user

# integracija

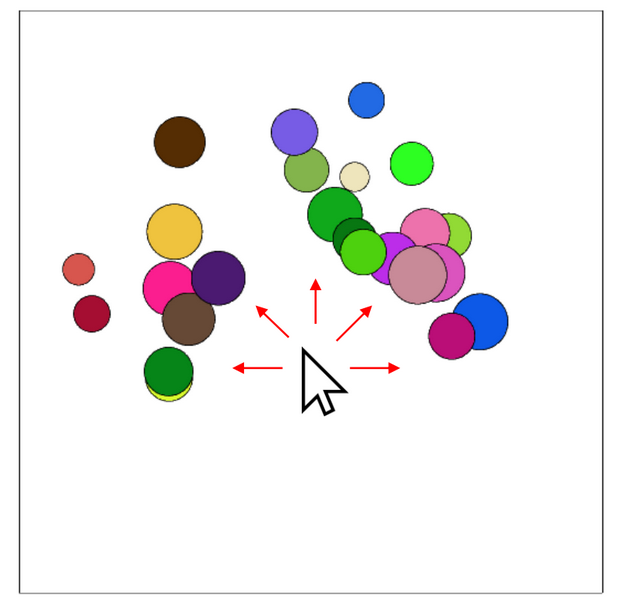
# ----------------------------------------------------------------------

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Rezultat:

Slika 7. Interaktivno kretanje