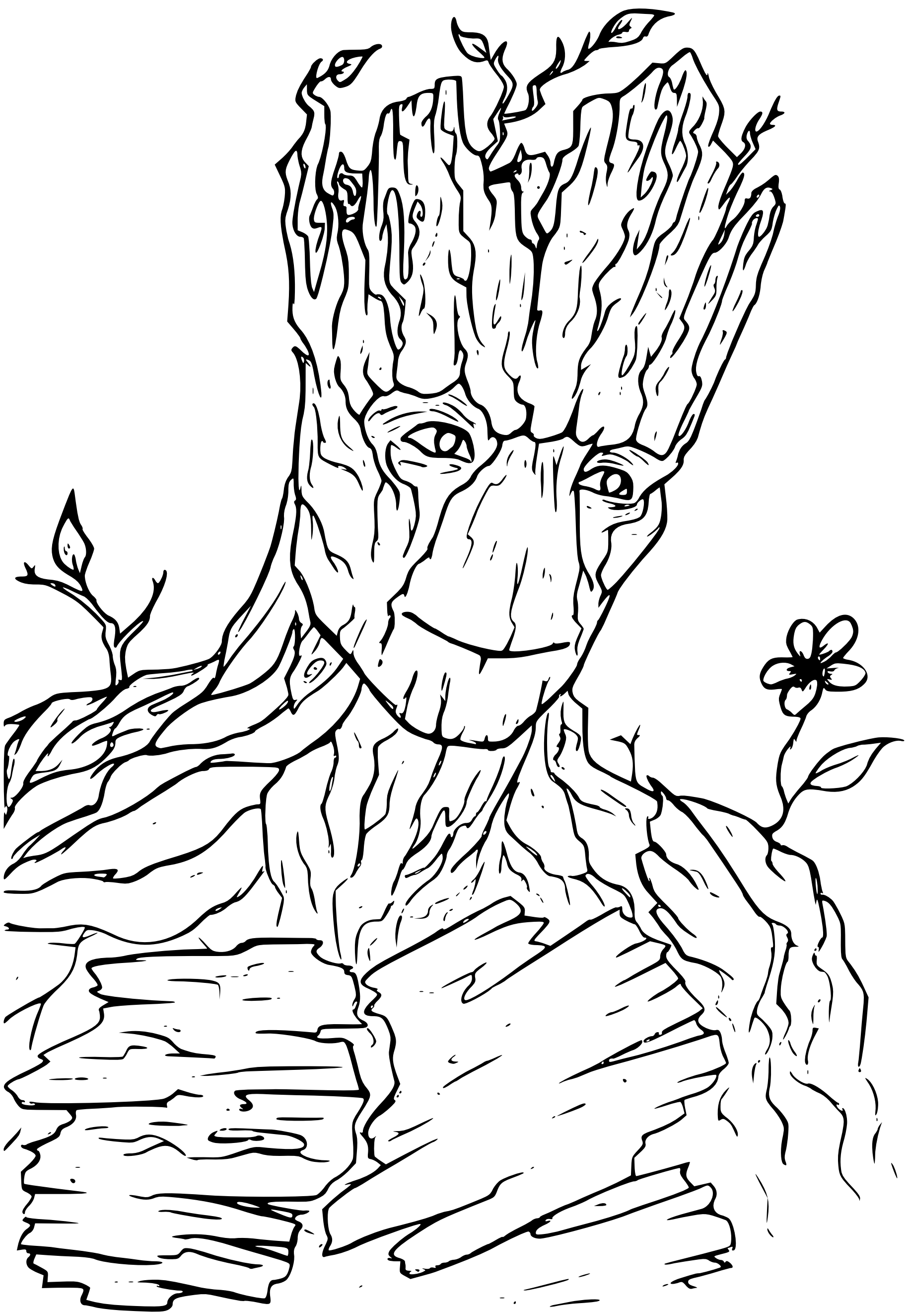
Name: ______________________________

Please answer the following questions in the space provided. In the case of multiple choice questions, please circle your answer clearly. If you run out of room to show work in the space provided, please make a note and continue work on the back. Show *all* your work, *even on multiple choice problems*! Groot luck!



(3) 1. Yondu's arrow zips around striking 3 separate targets. The first target is located at $\vec{\mathbf{r}}_1 = \langle 10, 2, 10 \rangle$m, the second at $\vec{\mathbf{r}}_2 = \langle 0, 0, -5 \rangle$m, and the third at $\vec{\mathbf{r}}_3 = \langle -4, 10, 2 \rangle$m. If the arrow initially started at Yondu located at the origin, and returns to Yondu after striking the final target. In which portion of its journey did the arrow travel the furthest?

A. Yondu to Target 1

**B. Target 1 to Target 2**

C. Target 2 to Target 3

D. Target 3 to Yondu

(2) 2. While entering the atmosphere of Xander, the Guardians ship experiences a variety of different forces. The force of gravity: $\vec{\mathbf{F}}_g = \langle 0, -30, 0 \rangle$ kN, the force of the engines: $\vec{\mathbf{F}}_{eng} = \langle 50, 20, 30 \rangle$ kN, and a shearing force due to strong winds: $\vec{\mathbf{F}}_{wind} = \langle 500, 0, 0 \rangle$ N. What is the net force experienced by the ship?

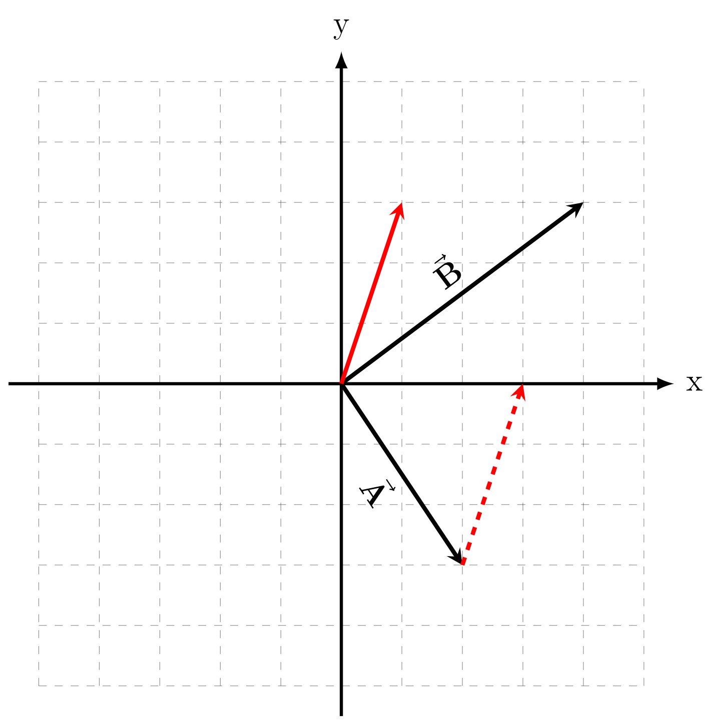
A. $\langle 55, -10, 30 \rangle$ kN

**B.** $\langle 50.5, -10, 30 \rangle$ kN

C. $\langle 500, 20, 30 \rangle$ kN

D. $\langle 50, 50, 35 \rangle$ kN

(2) 3. When the main computer breaks down, Rocket has to plan courses using old-school vectors. Given the two vectors below, sketch in the vector $\frac{1}{2}(\vec{\mathbf{B}} - \vec{\mathbf{A}})$.




(4) 4. Gamorra snaps off a quick leaping kick in which her foot is initially traveling at $10\,\mathrm{m/s}$ in the positive x direction. As her foot contacts her target, it slows to a stop in $2\,\mathrm{cm}$. Estimate the amount of time in which Gamorra's foot was interacting with the target.

**Solution:** We may be tempted to use the initial speed of Gamorra's foot to compute the time, but because it is slowing during the interaction, we should really use the arithmetic average velocity. So

$$\vec{\mathbf{v}}_{aavg,x} = \frac{10\,\mathrm{m/s} + 0\,\mathrm{m/s}}{2} = 5\,\mathrm{m/s}$$

Given that, it would take

$$\Delta t = \frac{\Delta r}{v_{aavg}} = \frac{0.02\,\mathrm{m}}{5\,\mathrm{m/s}} = 0.004\,\mathrm{s} = 4\,\mathrm{ms}$$

(6) 5. Drax the Destroyer leaps high into the air on his way to attempt to stab a beast to death from the inside. Being a supremely strong individual, his legs can take a magnitude of $10\,000\,\mathrm{N}$ before breaking. Suppose Drax ($100\,\mathrm{kg}$) was running forwards at $\langle 10, 0, 0\rangle\,\mathrm{m/s}$ before leaping with the maximum force his legs could take. Afterwards, his velocity is $\langle 20, 50, 0\rangle\,\mathrm{m/s}$. How long were Drax's feet in contact with the ground *during the course of his leap*? List and justify your various assumptions and simplifications!

**Solution:** This is mostly just a momentum principle exercise. We have the force and can work out the change in momentum, thereby solving for the unknown time of interaction.

$$\begin{aligned}
\vec{\mathbf{p}}_i &= (100\,\mathrm{kg})\,\langle 10, 0, 0\rangle\,\mathrm{m/s} = \langle 1000, 0, 0\rangle\,\mathrm{kg\,m/s} \\
\vec{\mathbf{p}}_f &= (100\,\mathrm{kg})\,\langle 20, 50, 0\rangle\,\mathrm{m/s} = \langle 2000, 5000, 0\rangle\,\mathrm{kg\,m/s} \\
\Delta\vec{\mathbf{p}} &= \vec{\mathbf{p}}_f - \vec{\mathbf{p}}_i = \langle 1000, 5000, 0\rangle\,\mathrm{kg\,m/s}
\end{aligned}$$

We only have the magnitude of the force, but know it would have to be in this same direction. To find the time, we'll just find the magnitude of the change in momentum and then divide by the magnitude of the force.

$$\begin{aligned}
|\Delta\vec{\mathbf{p}}| &= \sqrt{1000^2 + 5000^2} = 5099\mathrm{kg\,m/s} \\
\Rightarrow \Delta t &= \frac{|\Delta\vec{\mathbf{p}}|}{\left|\vec{\mathbf{F}}_{net}\right|} = \frac{5099}{10000} = 0.51\,\mathrm{s}
\end{aligned}$$

(8) 6. At the start of the first movie, Starlord gets himself out of a sticky situation by activating his rocket boots and sliding backwards on his back and out a hole in the wall. Suppose Starlord has a mass of 80 kg and his boots supply a horizontal force of 1000 N. The ground is a bit rough as he's sliding over it, so suppose he experiences a horizontal frictional force pointing in the opposite direction of his rocket force equal to 500 N. Starlord starts 25 m from the hole in the wall and needs to be out in under 2.5 seconds to avoid being shot. Use the iterative method with 0.5 second time intervals to determine whether Starlord will make it out in time. Show all your work!

**Solution:** Our net force is going to be:

$$\vec{\mathbf{F}}_{net} = (1000\,\mathrm{N})\hat{\mathbf{x}} - (500\,\mathrm{N})\hat{\mathbf{x}} = (500\,\mathrm{N})\hat{\mathbf{x}}$$

I'm going to start Starlord at the origin and assume he was starting from rest (really should have specified that...). The force isn't changing, so I just need to update the momentum and position each iteration. I'll use $\vec{\mathbf{v}}_{avg} \approx \frac{\vec{\mathbf{p}}_f}{m}$ for the velocity approximation, though in truth since the force was constant here I could have used the arithmetic average velocity and a bigger time interval.

$$
\begin{aligned}
p(0) &= 0 \\
r(0) &= 0
\end{aligned}
$$

$$
\begin{aligned}
p(0.5) &= p(0) + \vec{\mathbf{F}}_{net}\Delta t = 0 + 500(0.5) = 250 \\
r(0.5) &= r(0) + \frac{p(0.5)}{m}\Delta t = 0 + \frac{250}{80}(0.5) = 1.5625
\end{aligned}
$$

$$
\begin{aligned}
p(1) &= p(0.5) + \vec{\mathbf{F}}_{net}\Delta t = 250 + 500(0.5) = 500 \\
r(1) &= r(0.5) + \frac{p(1)}{m}\Delta t = 1.5625 + \frac{500}{80}(0.5) = 4.6875
\end{aligned}
$$

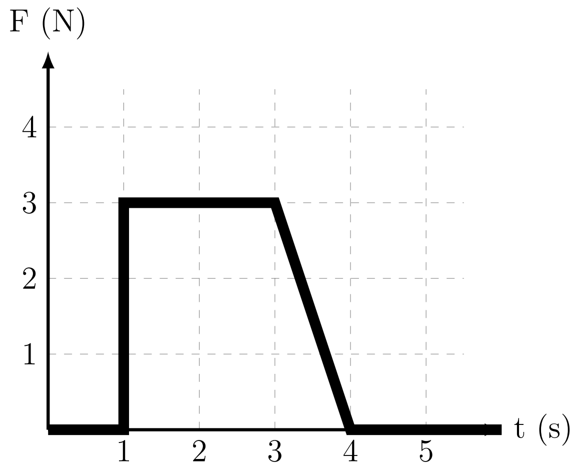
$$
\begin{aligned}
p(1.5) &= p(1) + \vec{\mathbf{F}}_{net}\Delta t = 500 + 500(0.5) = 750 \\
r(1.5) &= r(1) + \frac{p(1.5)}{m}\Delta t = 4.6875 + \frac{750}{80}(0.5) = 9.375
\end{aligned}
$$

$$
\begin{aligned}
p(2) &= p(1.5) + \vec{\mathbf{F}}_{net}\Delta t = 750 + 500(0.5) = 1000 \\
r(2) &= r(1.5) + \frac{p(1.5)}{m}\Delta t = 9.375 + \frac{1000}{80}(0.5) = 15.625
\end{aligned}
$$

$$
\begin{aligned}
p(2.5) &= p(2) + \vec{\mathbf{F}}_{net}\Delta t = 1000 + 500(0.5) = 1250 \\
r(2.5) &= r(2) + \frac{p(2)}{m}\Delta t = 9.375 + \frac{1250}{80}(0.5) = 23.4375
\end{aligned}
$$


Oh no! He doesn't quite make it! Fortunately, given movie villains, they'll probably miss anyway.

(2 (bonus)) 7. The below is a plot of a rocket thruster's force over time. If this is the only force acting on the rocket, what is the change in the rocket's momentum over the shown 5 seconds?




**Solution:** We know that the change in momentum is equal to $\vec{\mathbf{F}}_{net}\Delta t$, which is just called the impulse. And we know that in truth the impulse in the area beneath the force vs time plot. So here we could break the area up into a rectangular and triangular section, resulting in a total area of:

$$\text{Area } = (3\,\mathrm{N} \times 2\,\mathrm{s}) + \frac{(3\,\mathrm{N} \times 1\,\mathrm{s})}{2} = 7.5\,\mathrm{N\,s} = 7.5\,\mathrm{kg\,m/s}$$