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$$\lim_{x \rightarrow 0} \frac{\sqrt{2+x} - \sqrt{2}}{x} = \frac{\frac{1}{\sqrt{2+x}} + \frac{1}{\sqrt{2}}}{0} = \infty$$

$$\lim_{x \rightarrow 3} \frac{\sqrt{2x+1} - \sqrt{7}}{x} = \left[\frac{\frac{2}{\sqrt{2x+1}} + \frac{1}{\sqrt{7}}}{\frac{1}{x^2}} \right]$$

$$\lim_{x \rightarrow 2} \frac{x^2 + x - 8}{x(x-2)} = \frac{x+4}{x+2}$$

$$\lim_{x \rightarrow 0} \frac{x^2}{x(\sqrt{1-4x^2})} = \frac{x}{\sqrt{1-4x^2}}$$

$$\lim_{x \rightarrow 0} \frac{1}{\sqrt{2x+1}-\sqrt{2}} = \frac{1}{\sqrt{2}-\sqrt{2}} = \boxed{\frac{1}{2-\sqrt{2}}}$$

$$51. \lim_{x \rightarrow 4} \frac{x-4}{x^2-16}$$

$$\frac{x-4}{(x+4)(x-4)} \quad \frac{1}{x+4}$$

$$\frac{1}{4+4} \quad \lim_{x \rightarrow 4} = \frac{1}{8}$$

Examples: Find the limit.

$$1. \lim_{x \rightarrow 1} (-x^2 + 1) = -(1)^2 + 1 = \boxed{0}$$

$$2. \lim_{x \rightarrow -3} \frac{2x-3}{x+5} = \frac{\lim_{x \rightarrow -3} (2x-3)}{\lim_{x \rightarrow -3} (x+5)} = \frac{\cancel{\lim_{x \rightarrow -3} (2x)}}{\cancel{\lim_{x \rightarrow -3} (x+5)}} - \frac{\lim_{x \rightarrow -3} 3}{\lim_{x \rightarrow -3} 5}$$

$\cancel{\lim_{x \rightarrow -3}}$

$$= \frac{2 \lim_{x \rightarrow -3} x - \cancel{\lim_{x \rightarrow -3} 3}}{\cancel{\lim_{x \rightarrow -3} x + \cancel{\lim_{x \rightarrow -3} 5}}} = \frac{2(-3) - 3}{-3 + 5} = \boxed{\frac{-9}{2}}$$

1.3 Evaluating Limits Analytically

Example 5

Evaluate the limit analytically:
 $\lim_{x \rightarrow 0^+} \frac{1 - \tan x}{\ln x}$

$$\begin{aligned}
 \lim_{x \rightarrow \pi/4} \frac{1 - \tan x}{\sin x - \cos x} &= \lim_{x \rightarrow \pi/4} \frac{\frac{\sin x}{\cos x}}{\sin x - \cos x} \cdot \frac{\cos x}{\cos x} \quad \text{Eliminate the embedded fraction} \\
 &= \lim_{x \rightarrow \pi/4} \frac{\cos x - \sin x}{(\sin x - \cos x)\cos x} \\
 &= \lim_{x \rightarrow \pi/4} \frac{-(\sin x - \cos x)}{(\sin x - \cos x)\cos x} \quad \text{If the subtraction is backwards, Factoring a negative 1 to flip the signs} \\
 &= \lim_{x \rightarrow \pi/4} \frac{-1}{\cos x} \\
 &= \frac{-1}{\cos(\frac{\pi}{4})} \quad \text{Direct substitution} \\
 &= \frac{-1}{\sqrt{2}/2} = -\sqrt{2}
 \end{aligned}$$

The key takeaway from this part of the activity is that there is a sudden jump in the curve at $t=12$. Direct Substitution (Try this FIRST) 2. This is intentional! In Precalculus the goal is to build a conceptual framework around the big idea of limits and to explore at length the variety of strategies we have to evaluate limits and when each one might be appropriate. Example: Always check for substitution first. Strategies for Finding Limits To find limits analytically, try the following: 1. Students should realize the need to use a hole as a placeholder when beginning the linear graph. When there is no hole, gap, or asymptote in the graph, the actual y-value of the function and the intended y-value (the limit) are actually the same, so evaluating the function by direct substituting also gives the value of the limit! We use the language of a "well-behaved" function to talk about functions that act predictably and "play nice". Be looking for students that try to draw a vertical or very steep line to get from the constant rate to the linear rate. Find: Direct Substitution One of the easiest and most useful ways to evaluate a limit analytically is direct substitution (substitution and evaluation): If you can plug c into $f(x)$ and generate a real number answer in the range of $f(x)$, that generally implies that the limit exists (assuming $f(x)$ is continuous at c). If the f and g are functions such that the limit of the composition is: If c is a real number in the domain of a trigonometric function then: Example Direct Substitution can be used since the function is well defined at $x=3$ For what value(s) of x can the limit not be evaluated using direct substitution? Section 1. In yesterday's card sort, most groups matched the limits to the graph and then the equations to the graphs. Then use Direct Substitution. Example Evaluate the limit analytically: If x is the input of the sine function then $\lim_{x \rightarrow 3} \sin x$ is the output of the sine function. Then $\lim_{x \rightarrow 3} \sin x = \sin 3$. Now, we can evaluate the limit using direct substitution. If $x = 3$, then $\sin 3 \approx 0.1411$. So, $\lim_{x \rightarrow 3} \sin x \approx 0.1411$. Note: We can also evaluate this limit using the squeeze theorem, which states that if $f(x) \leq g(x) \leq h(x)$ for all x near c , and $\lim_{x \rightarrow c} f(x) = \lim_{x \rightarrow c} h(x) = L$, then $\lim_{x \rightarrow c} g(x) = L$. For our example, we can choose $f(x) = -1$, $g(x) = \sin x$, and $h(x) = 1$. As $x \rightarrow 3$, $f(x) \leq g(x) \leq h(x)$. Since $\lim_{x \rightarrow 3} f(x) = \lim_{x \rightarrow 3} h(x) = 0$, by the squeeze theorem, $\lim_{x \rightarrow 3} \sin x = 0$. Now, let's look at some examples where direct substitution does not work. Example 1: Evaluate $\lim_{x \rightarrow 2} \frac{x^2 - 4}{x - 2}$. If we substitute $x = 2$ into the numerator and denominator, we get $\frac{0}{0}$, which is undefined. This is called an indeterminate form. To evaluate this limit, we can factor the numerator: $\lim_{x \rightarrow 2} \frac{(x-2)(x+2)}{x-2}$. Now, we can cancel the common factor of $(x-2)$ in the numerator and denominator: $\lim_{x \rightarrow 2} (x+2)$. Substituting $x = 2$ into the simplified expression, we get 4 . So, $\lim_{x \rightarrow 2} \frac{x^2 - 4}{x - 2} = 4$. Example 2: Evaluate $\lim_{x \rightarrow 0} \frac{\sin x}{x}$. If we substitute $x = 0$ into the numerator and denominator, we get $\frac{0}{0}$, which is undefined. This is another indeterminate form. To evaluate this limit, we can use the fact that $\lim_{x \rightarrow 0} \frac{\sin x}{x} = 1$. This is a well-known limit that can be proven using the squeeze theorem or L'Hopital's rule. So, $\lim_{x \rightarrow 0} \frac{\sin x}{x} = 1$. Example 3: Evaluate $\lim_{x \rightarrow 1} \frac{x^2 - 1}{x - 1}$. If we substitute $x = 1$ into the numerator and denominator, we get $\frac{0}{0}$, which is undefined. This is an indeterminate form. To evaluate this limit, we can factor the numerator: $\lim_{x \rightarrow 1} \frac{(x-1)(x+1)}{x-1}$. Now, we can cancel the common factor of $(x-1)$ in the numerator and denominator: $\lim_{x \rightarrow 1} (x+1)$. Substituting $x = 1$ into the simplified expression, we get 2 . So, $\lim_{x \rightarrow 1} \frac{x^2 - 1}{x - 1} = 2$. Example 4: Evaluate $\lim_{x \rightarrow 0} \frac{e^x - 1}{x}$. If we substitute $x = 0$ into the numerator and denominator, we get $\frac{0}{0}$, which is undefined. This is an indeterminate form. To evaluate this limit, we can use L'Hopital's rule, which states that if $\lim_{x \rightarrow c} f(x) = \lim_{x \rightarrow c} g(x) = 0$ or $\pm\infty$, then $\lim_{x \rightarrow c} \frac{f(x)}{g(x)} = \lim_{x \rightarrow c} \frac{f'(x)}{g'(x)}$, provided that the limit exists. In this case, $\lim_{x \rightarrow 0} e^x - 1 = 0$ and $\lim_{x \rightarrow 0} x = 0$, so we can apply L'Hopital's rule: $\lim_{x \rightarrow 0} \frac{e^x - 1}{x} = \lim_{x \rightarrow 0} \frac{e^x}{1} = \lim_{x \rightarrow 0} e^x = 1$. So, $\lim_{x \rightarrow 0} \frac{e^x - 1}{x} = 1$. Example 5: Evaluate $\lim_{x \rightarrow 0} \frac{\tan x}{x}$. If we substitute $x = 0$ into the numerator and denominator, we get $\frac{0}{0}$, which is undefined. This is an indeterminate form. To evaluate this limit, we can use L'Hopital's rule: $\lim_{x \rightarrow 0} \frac{\tan x}{x} = \lim_{x \rightarrow 0} \frac{\sec^2 x}{1} = \lim_{x \rightarrow 0} \sec^2 x = 1$. So, $\lim_{x \rightarrow 0} \frac{\tan x}{x} = 1$. Example 6: Evaluate $\lim_{x \rightarrow 0} \frac{\sin x}{\tan x}$. If we substitute $x = 0$ into the numerator and denominator, we get $\frac{0}{0}$, which is undefined. This is an indeterminate form. To evaluate this limit, we can use L'Hopital's rule: $\lim_{x \rightarrow 0} \frac{\sin x}{\tan x} = \lim_{x \rightarrow 0} \frac{\cos x}{\sec^2 x} = \lim_{x \rightarrow 0} \frac{\cos x}{1} = \lim_{x \rightarrow 0} \cos x = 1$. So, $\lim_{x \rightarrow 0} \frac{\sin x}{\tan x} = 1$. Example 7: Evaluate $\lim_{x \rightarrow 0} \frac{\ln(1+x)}{x}$. If we substitute $x = 0$ into the numerator and denominator, we get $\frac{0}{0}$, which is undefined. This is an indeterminate form. To evaluate this limit, we can use L'Hopital's rule: $\lim_{x \rightarrow 0} \frac{\ln(1+x)}{x} = \lim_{x \rightarrow 0} \frac{\frac{1}{1+x}}{1} = \lim_{x \rightarrow 0} \frac{1}{1+x} = \lim_{x \rightarrow 0} 1 = 1$. So, $\lim_{x \rightarrow 0} \frac{\ln(1+x)}{x} = 1$. Example 8: Evaluate $\lim_{x \rightarrow 0} \frac{e^x - 1 - x}{x^2}$. If we substitute $x = 0$ into the numerator and denominator, we get $\frac{0}{0}$, which is undefined. This is an indeterminate form. To evaluate this limit, we can use L'Hopital's rule: $\lim_{x \rightarrow 0} \frac{e^x - 1 - x}{x^2} = \lim_{x \rightarrow 0} \frac{e^x - 1}{2x} = \lim_{x \rightarrow 0} \frac{e^x}{2} = \lim_{x \rightarrow 0} \frac{1}{2} = \frac{1}{2}$. So, $\lim_{x \rightarrow 0} \frac{e^x - 1 - x}{x^2} = \frac{1}{2}$.

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