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If there exist constants $c > 0$, $n_0 > 0$ such that for all $n \geqslant n_0$:

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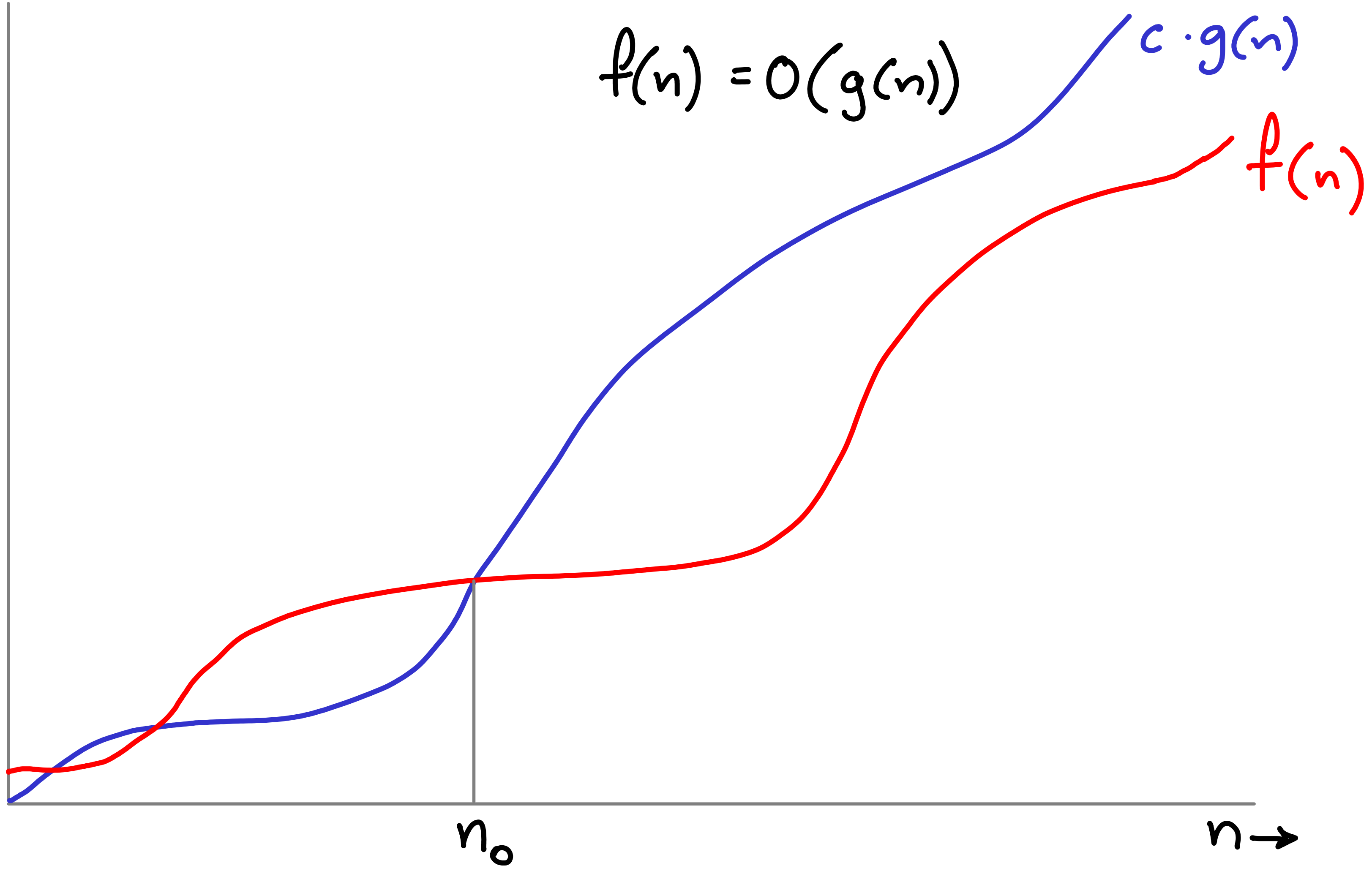
then we say $f(n) = O(g(n))$ Big-O

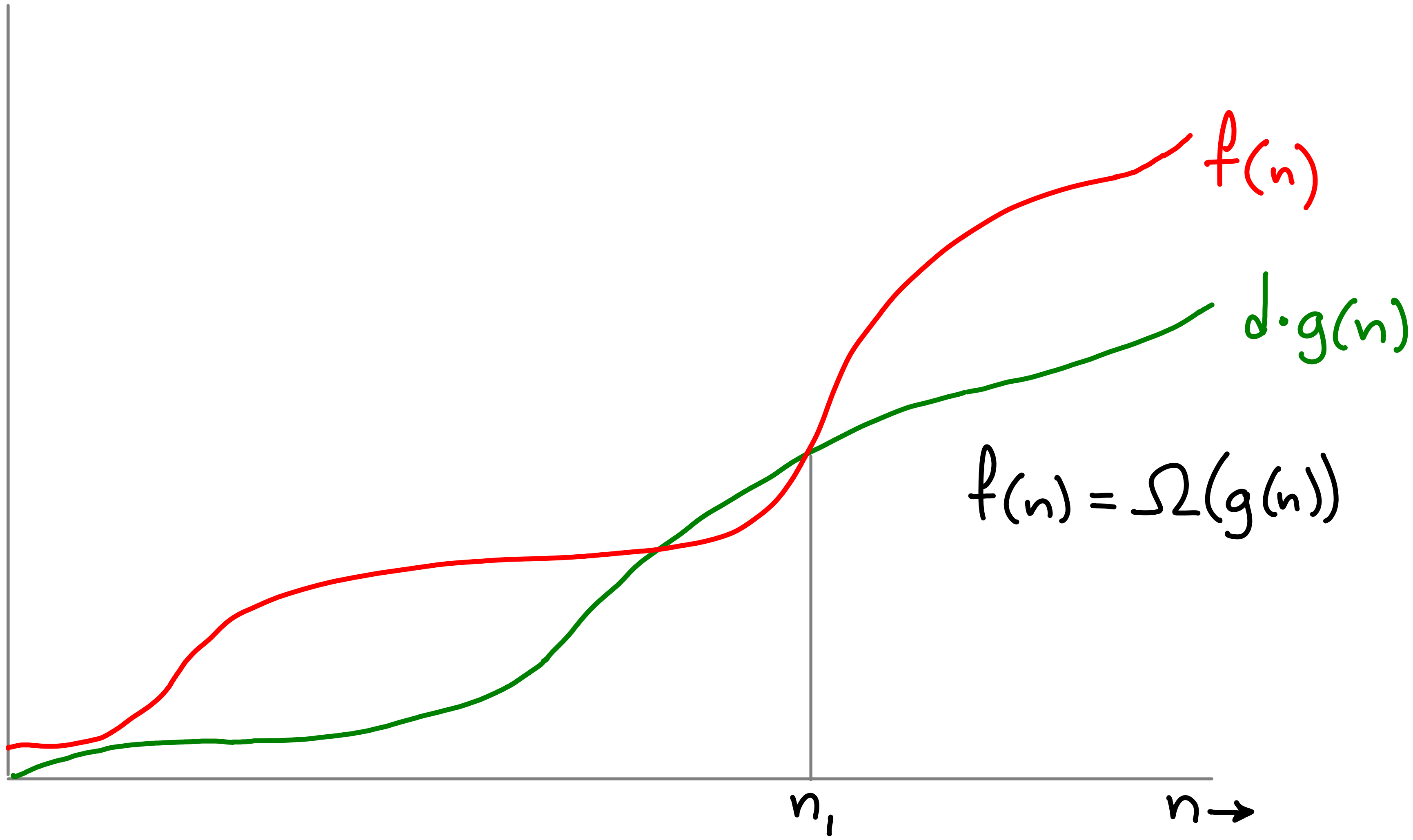
If there exist constants $d > 0$, $n_1 > 0$ such that for all $n \geqslant n_0$:

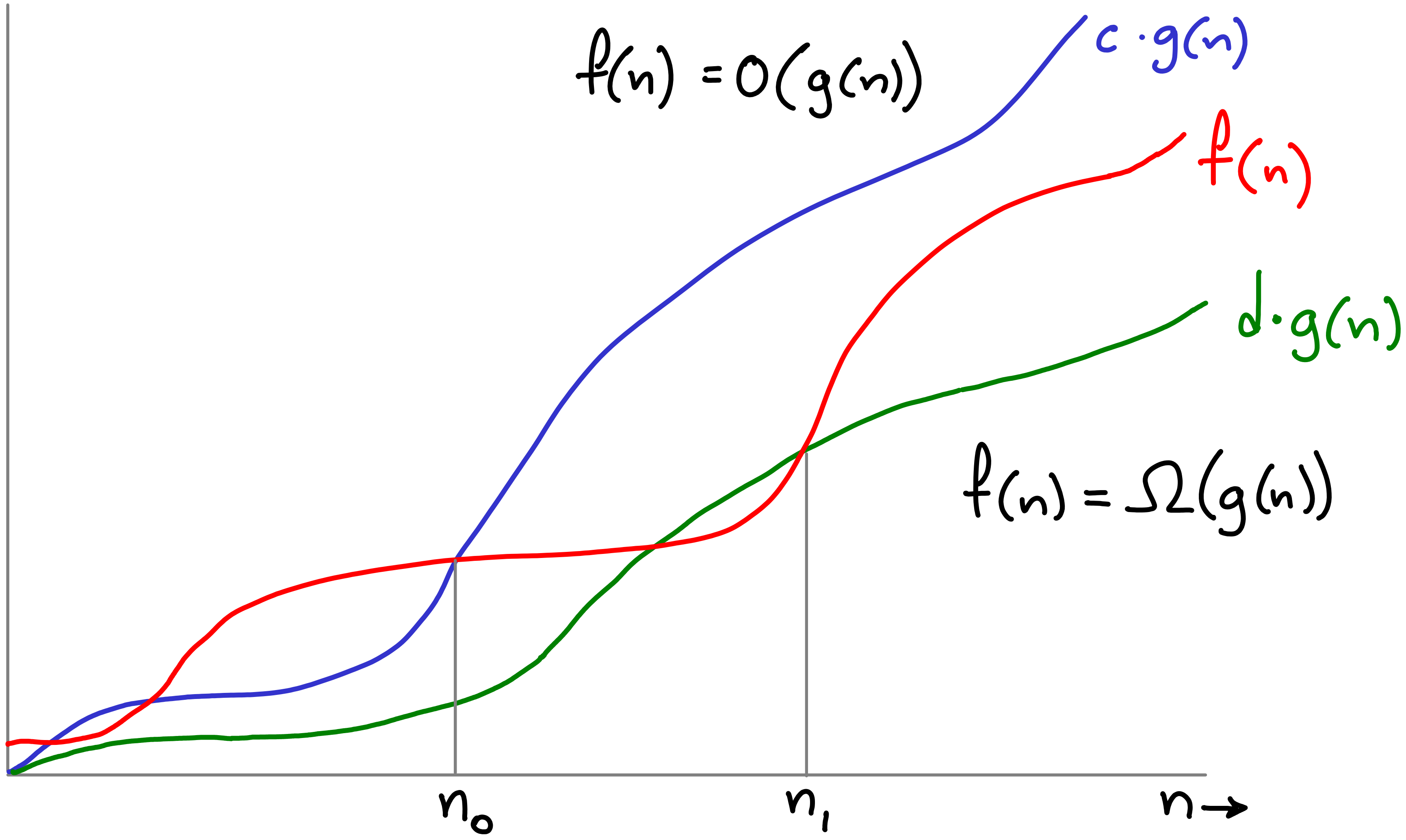
$$f(n) \geqslant d \cdot g(n)$$

then we say $f(n) = \Omega(g(n))$ Omega



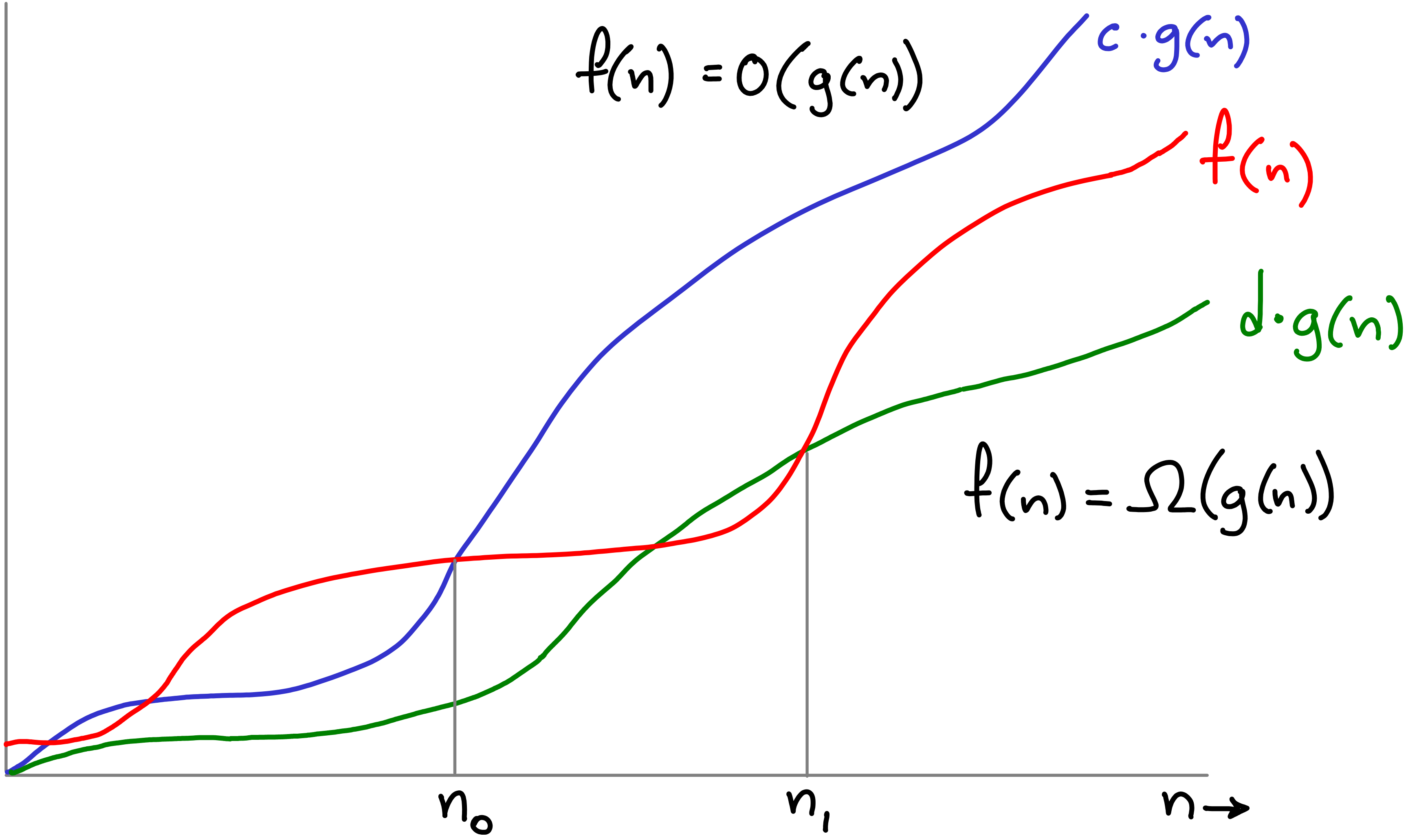
f(n) = O(g(n))
c · g(n)
f(n)
n₀
n →

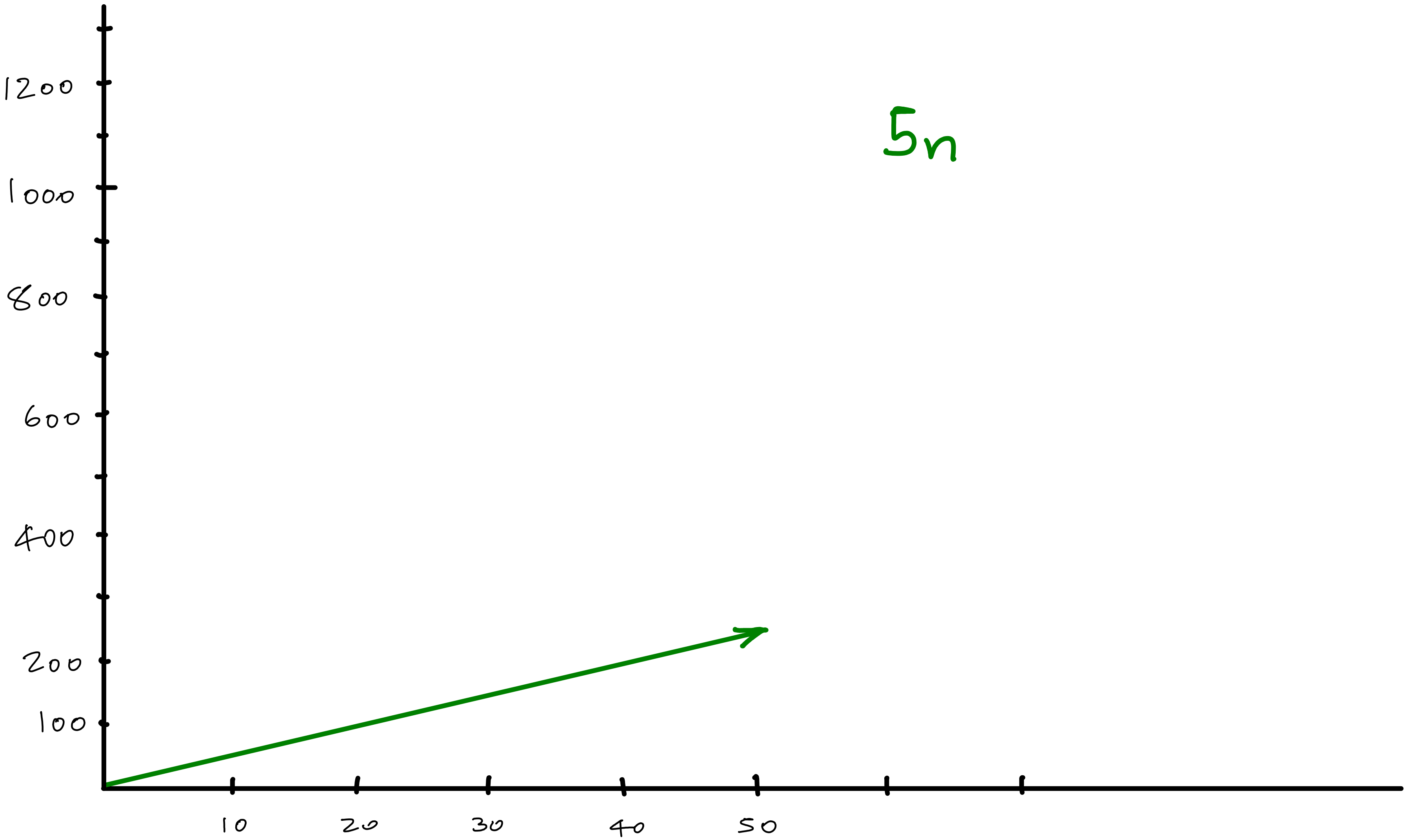

f(n)
d·g(n)
f(n) = Ω(g(n))
n₁
n →



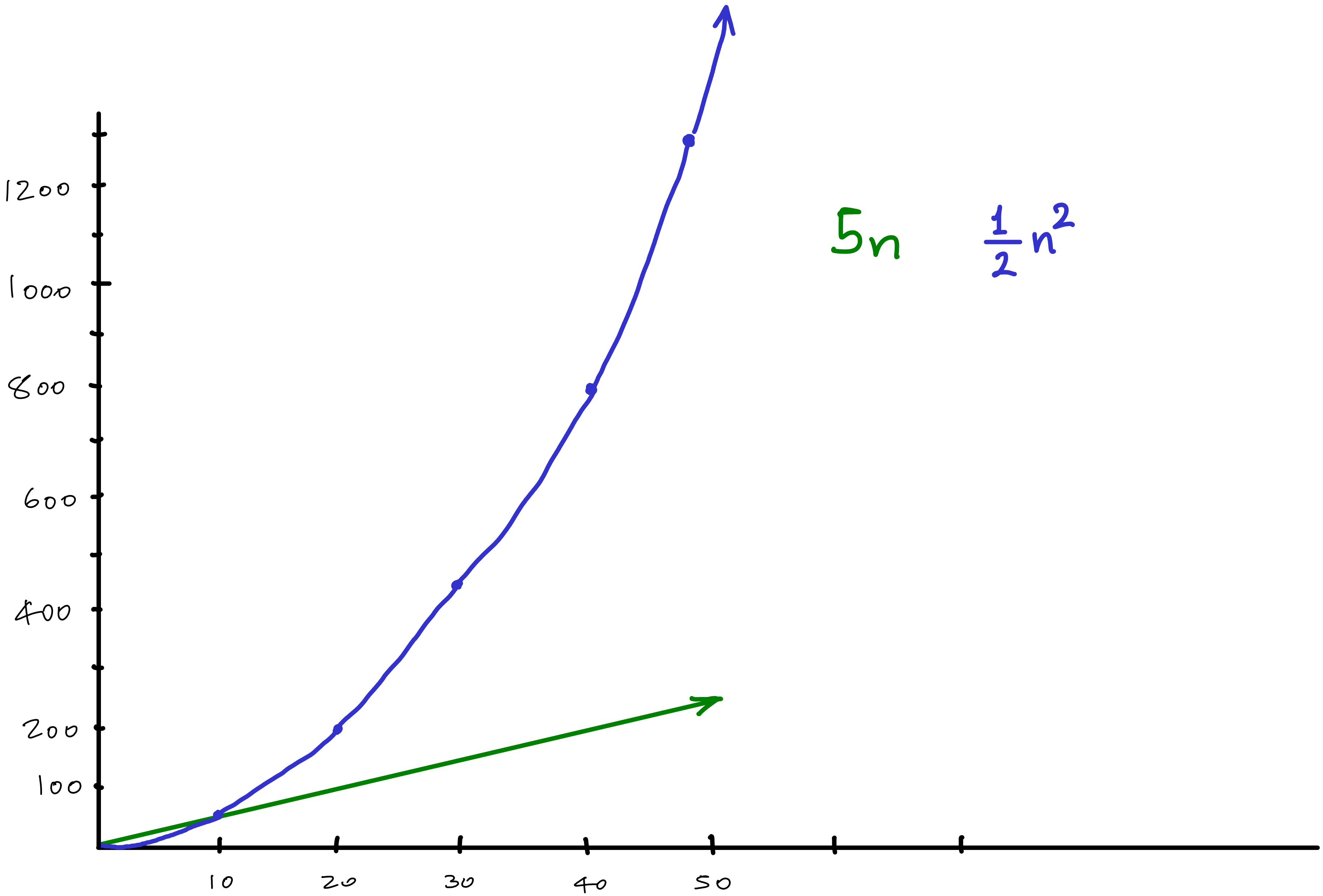
$f(n) = O(g(n))$
$c \cdot g(n)$
$f(n)$
$d \cdot g(n)$
$f(n) = \Omega(g(n))$
n_0
n_1
$n \rightarrow$

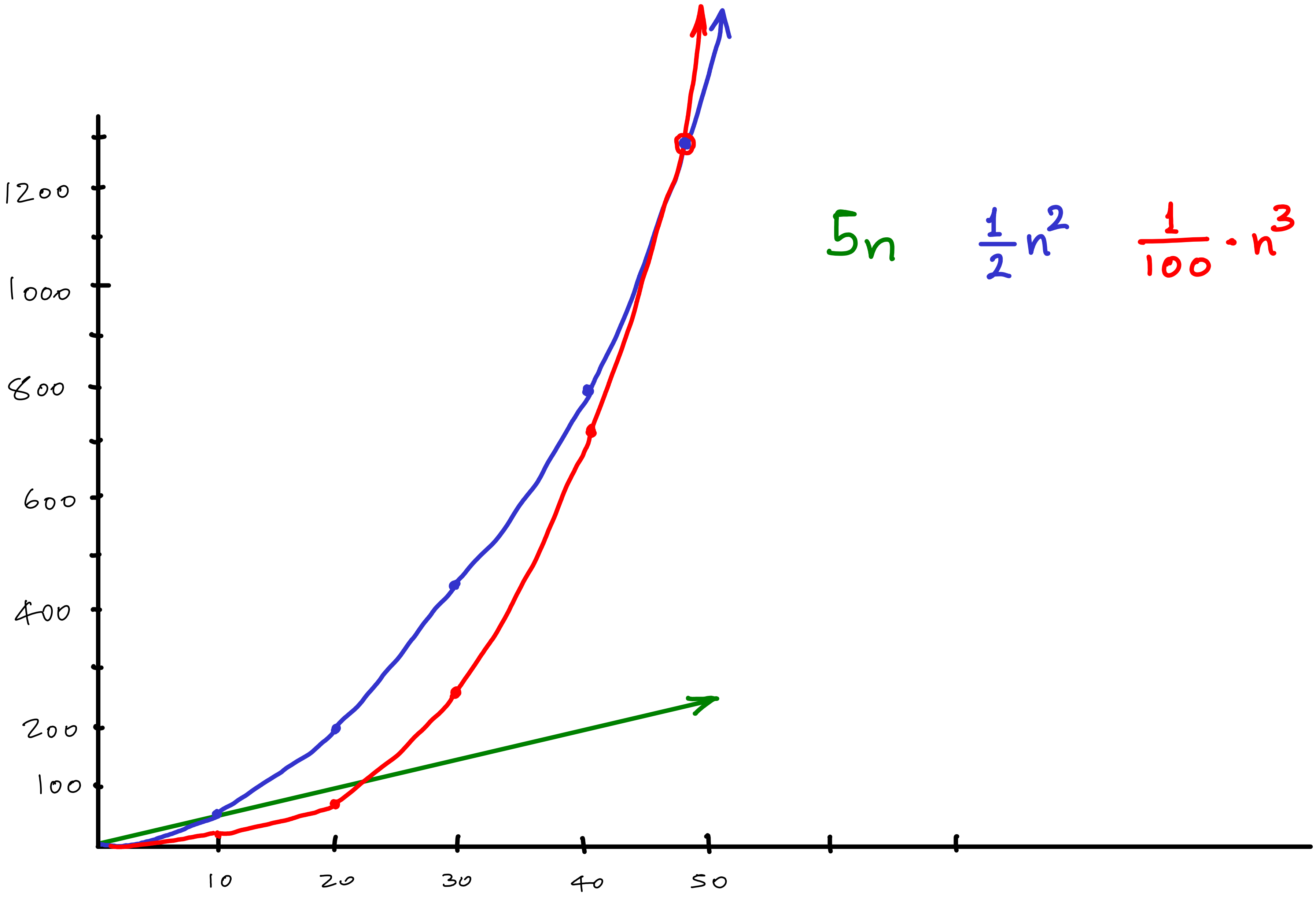
If $f(n) = O(g(n))$ AND $f(n) = \Omega(g(n))$ then $f(n) = \Theta(g(n))$ [Theta]





5n
1200
1000
800
600
400
200
100
10
20
30
40
50


1200
1000
800
600
400
200
100
10
20
30
40
50
$5n$
$\frac{1}{2}n^2$



1200
1000
800
600
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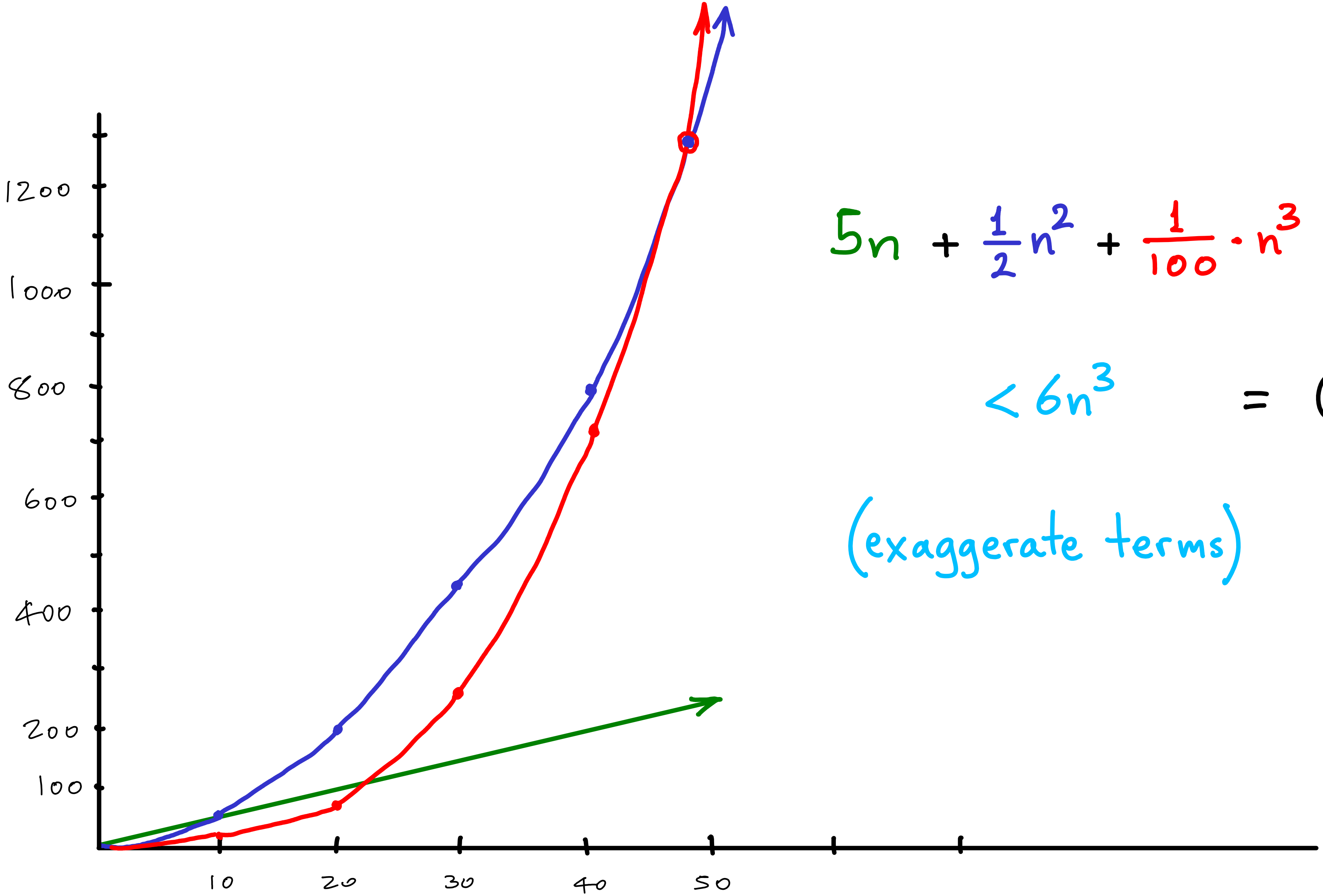
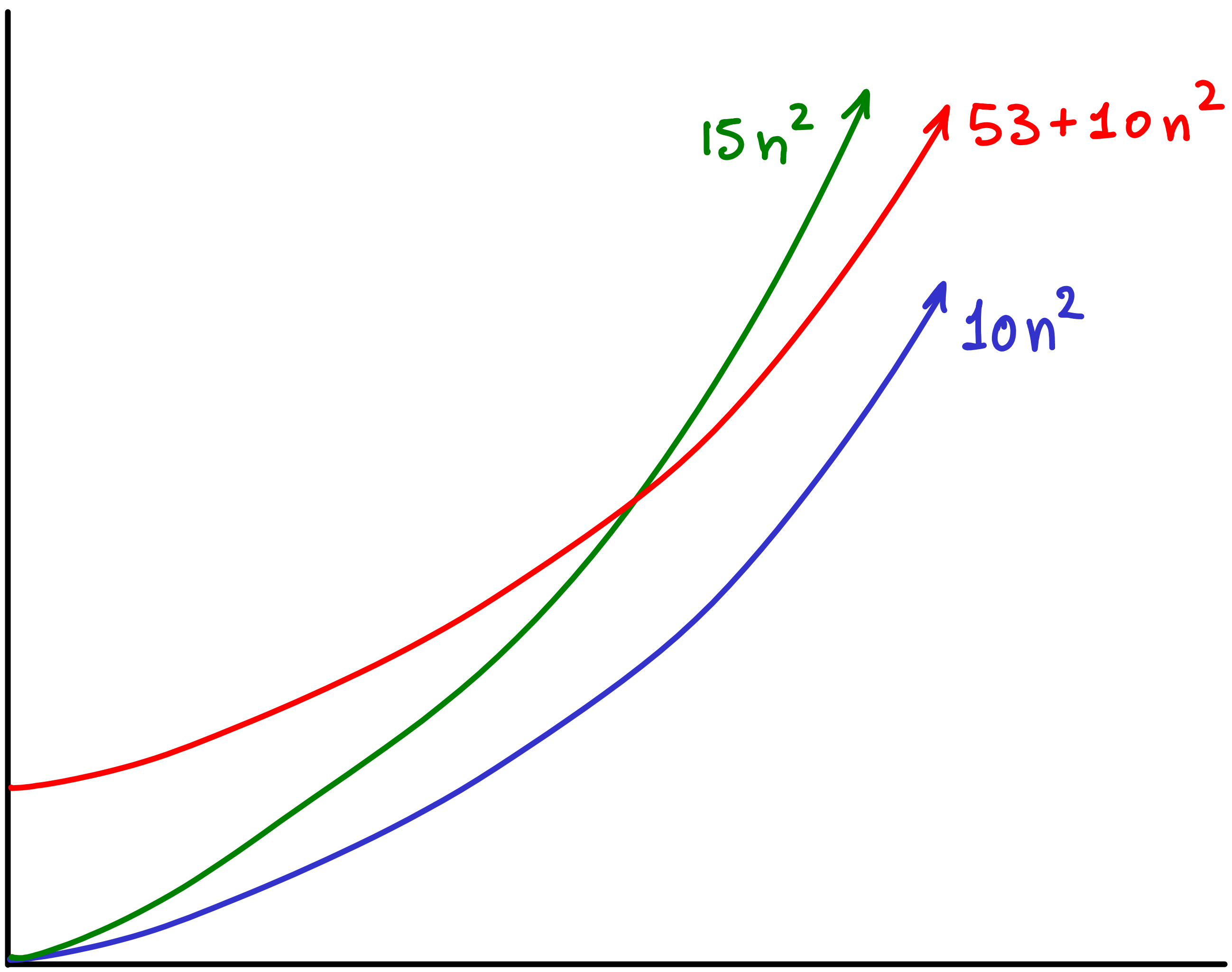
100
10
20
30
40
50
5n
1/2 n^2
1/100 · n^3



$$5n + \frac{1}{2}n^2 + \frac{1}{100}\cdot n^3$$

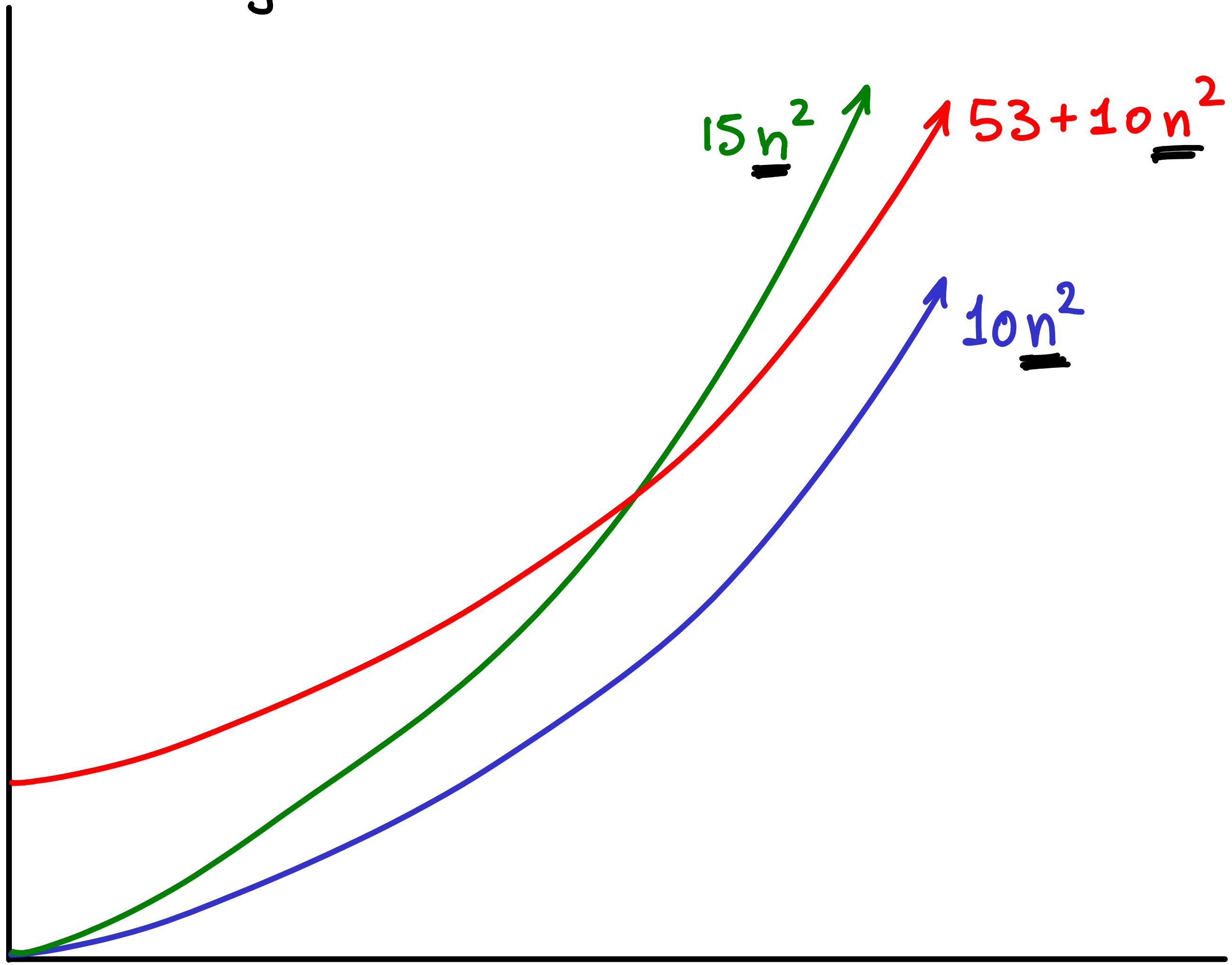
$$< 6n^3 \quad = O(n^3)$$

(exaggerate terms)



$15n^2$
$53+10n^2$
$10n^2$

For large n these are within a constant multiplicative factor



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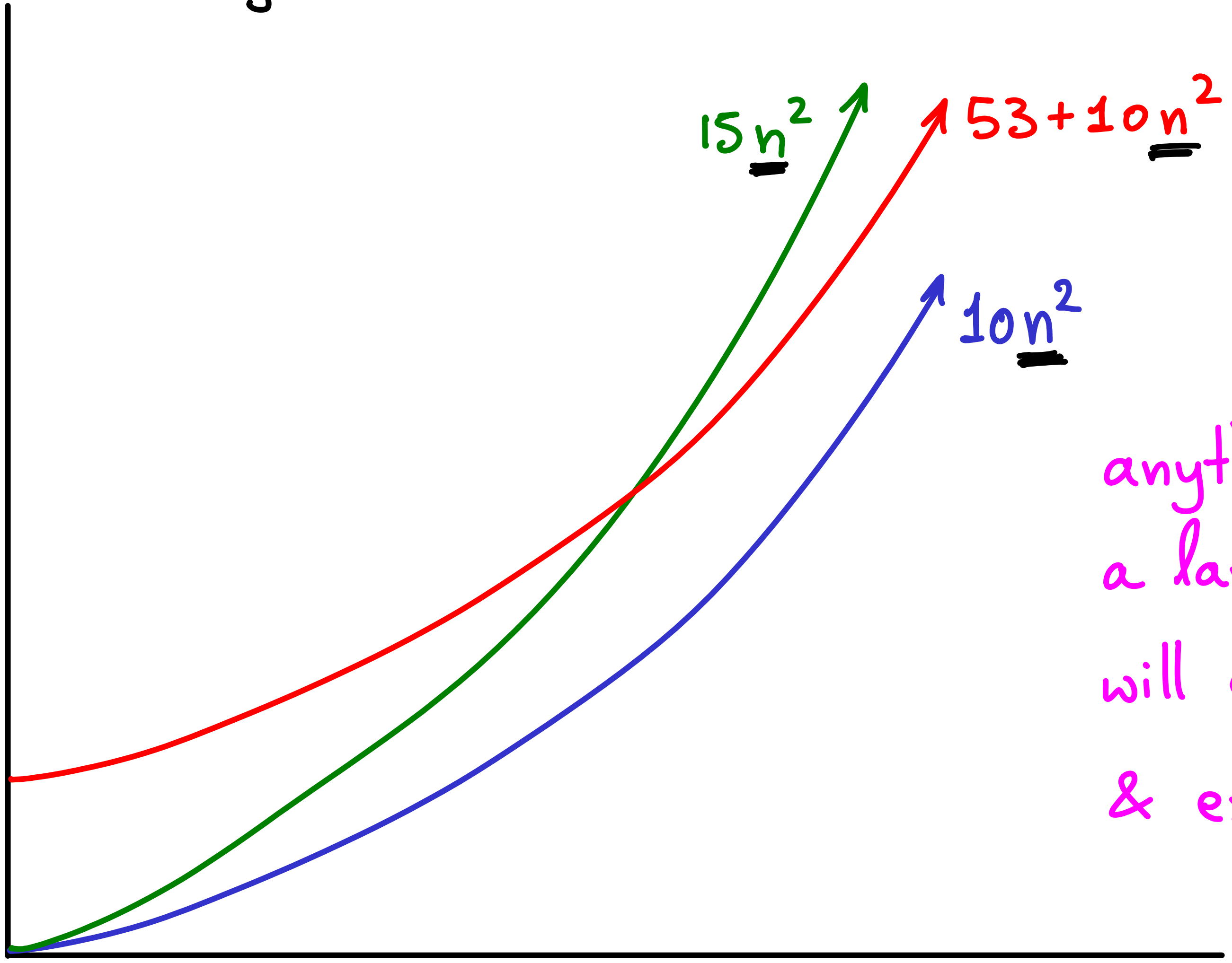
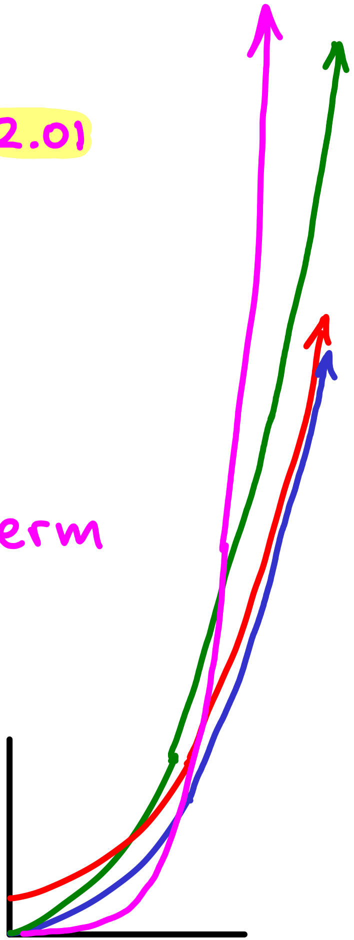


$0.00001 \cdot n^{2.01}$

anything with
a larger dominating term
will eventually surpass
& exceed by a lot.



Polynomials: $a + bn + cn^2 + dn^3 \cdots + zn^k$

$a, b, c, d, \ldots, z$: constants

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Also assuming one of each term (compare to: $a_1 n + a_2 n + \cdots + a_n n$)

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Logarithms: $50 \cdot \log n^3 + \log^{20} n + n^{0.1} = O(n^{0.1})$

"weaker" than polynomial

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"weaker" than polynomial

Exponential: $100 \cdot n^{50} + \underline{3}^n + 40 \cdot 2^n = O(\underline{3}^n)$

"stronger" than polynomial

Ordering some common functions

Within each row, subdivide

n^n

$n!$

exponential: k^n $(k>1)$ $\quad$ 1.1^n, 2^n, 3^n etc

polynomial: n^k $\quad$ $n^{0.1}$, $\sqrt{n}$, n, $n^{1.1}$, n^2, n^3, etc

powers of logs: $\log^k n = (\log n)^k$ $\quad$ $\log n$, $\log^2 n$, $\log^3 n$, etc

base doesn't matter!

constants: $1,\ 50,\ 2^{100} = O(1)$

$$\left(50 \cdot \log n + 10\log^5 n + n^{0.1}\right) \cdot \left(100 \cdot n^{50} + 3^n + 40 \cdot 2^n\right) = ?$$

$$\left(50 \cdot \log n + 10 \log^5 n + n^{0.1}\right) \cdot \left(100 \cdot n^{50} + 3^n + 40 \cdot 2^n\right) =$$

$$O(n^{0.1}) \cdot O(3^n) \quad = \quad ?$$

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$$O(n^{0.1}) \cdot O(3^n) \quad = O(n^{0.1} \cdot 3^n)$$

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- is $5n^2 = O(n^3)$? yes. but a better answer is $O(n^2)$

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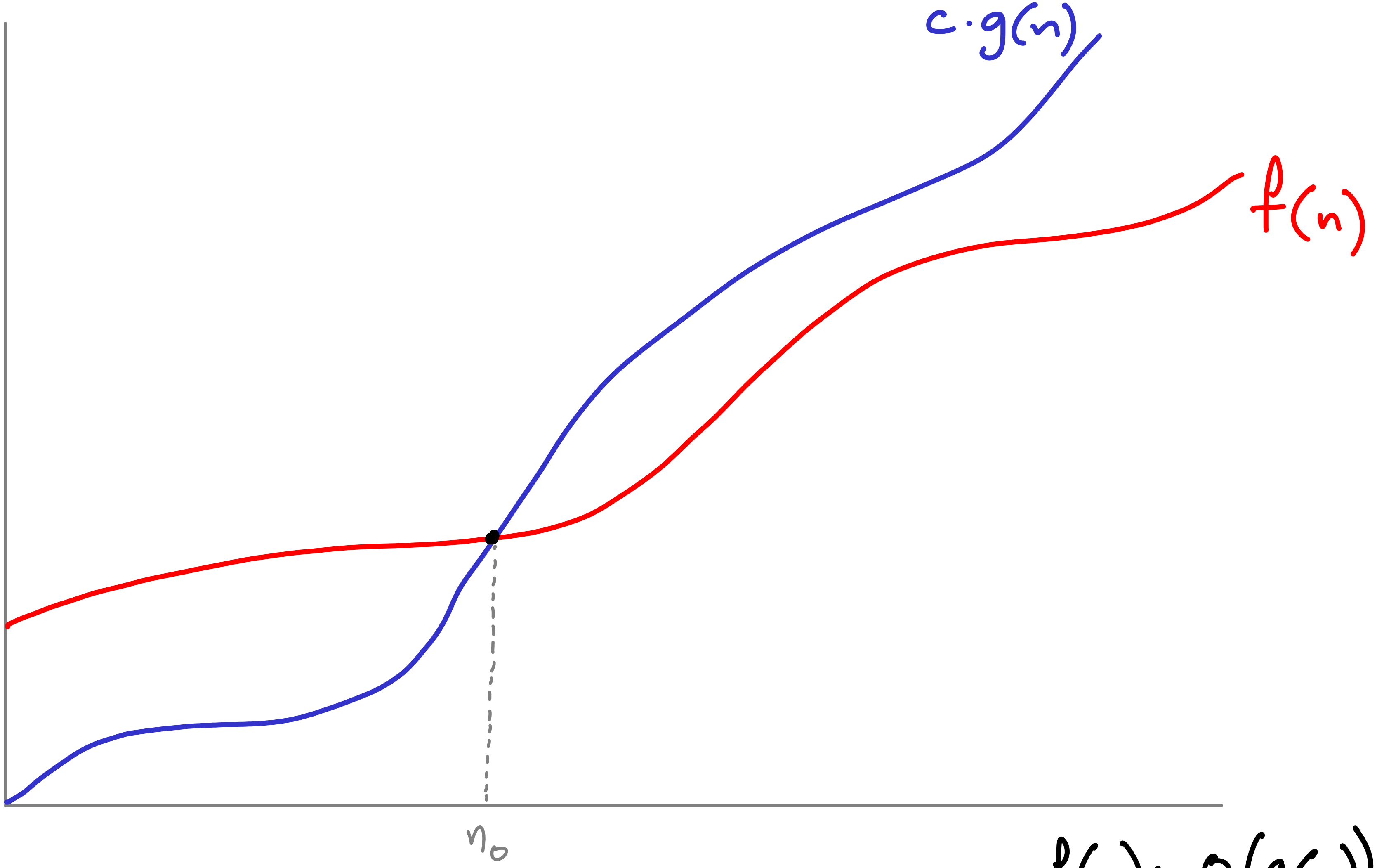
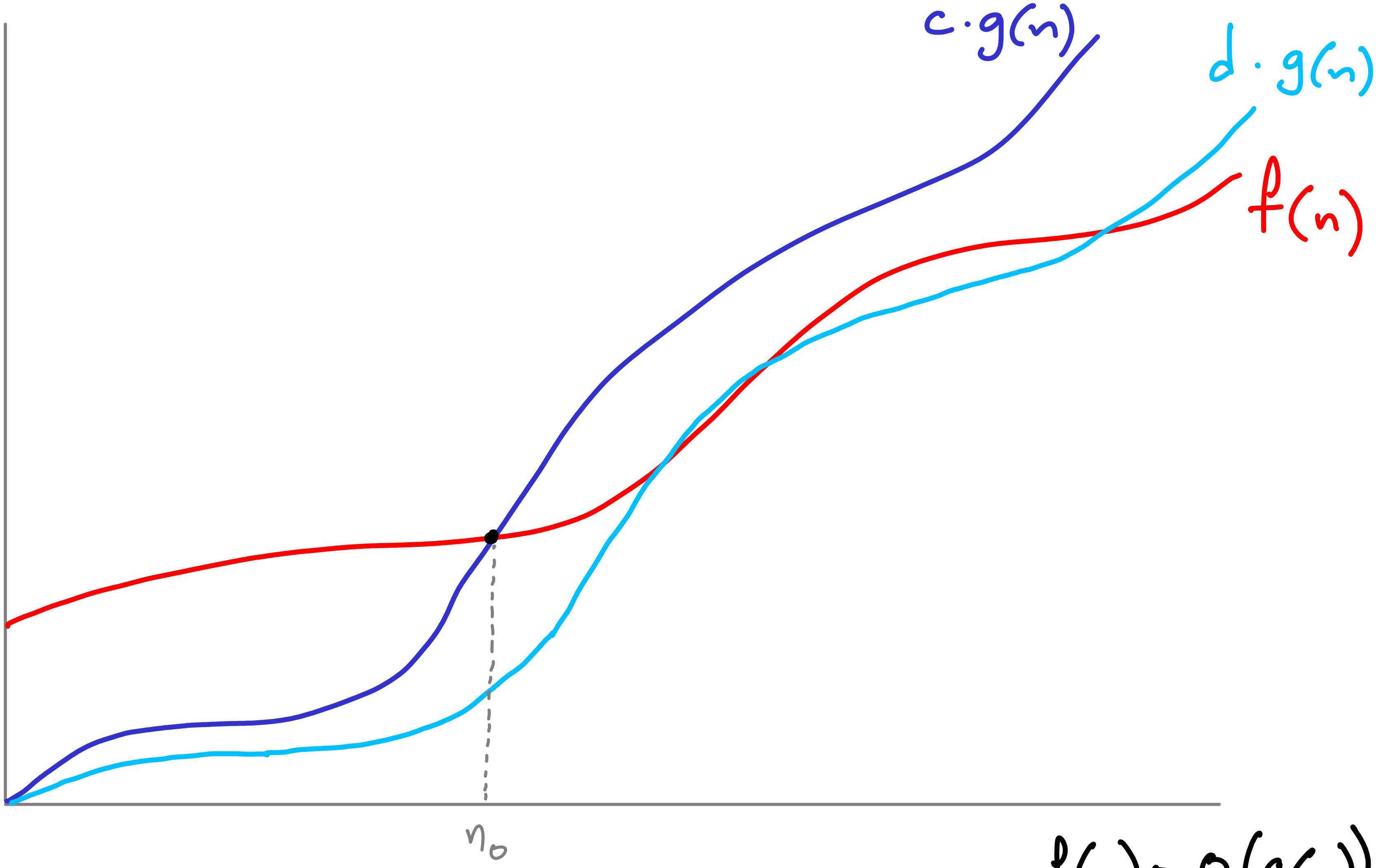
- is $5n^2 = O(n^3)$? yes. but a better answer is $O(n^2)$
- is $n^3 = O(5n^2)$? No.

There is no c such that $n^3 \leq c\cdot 5n^2$
(for all large n)

Also, the 5 doesn't belong in $O(5n^2)$



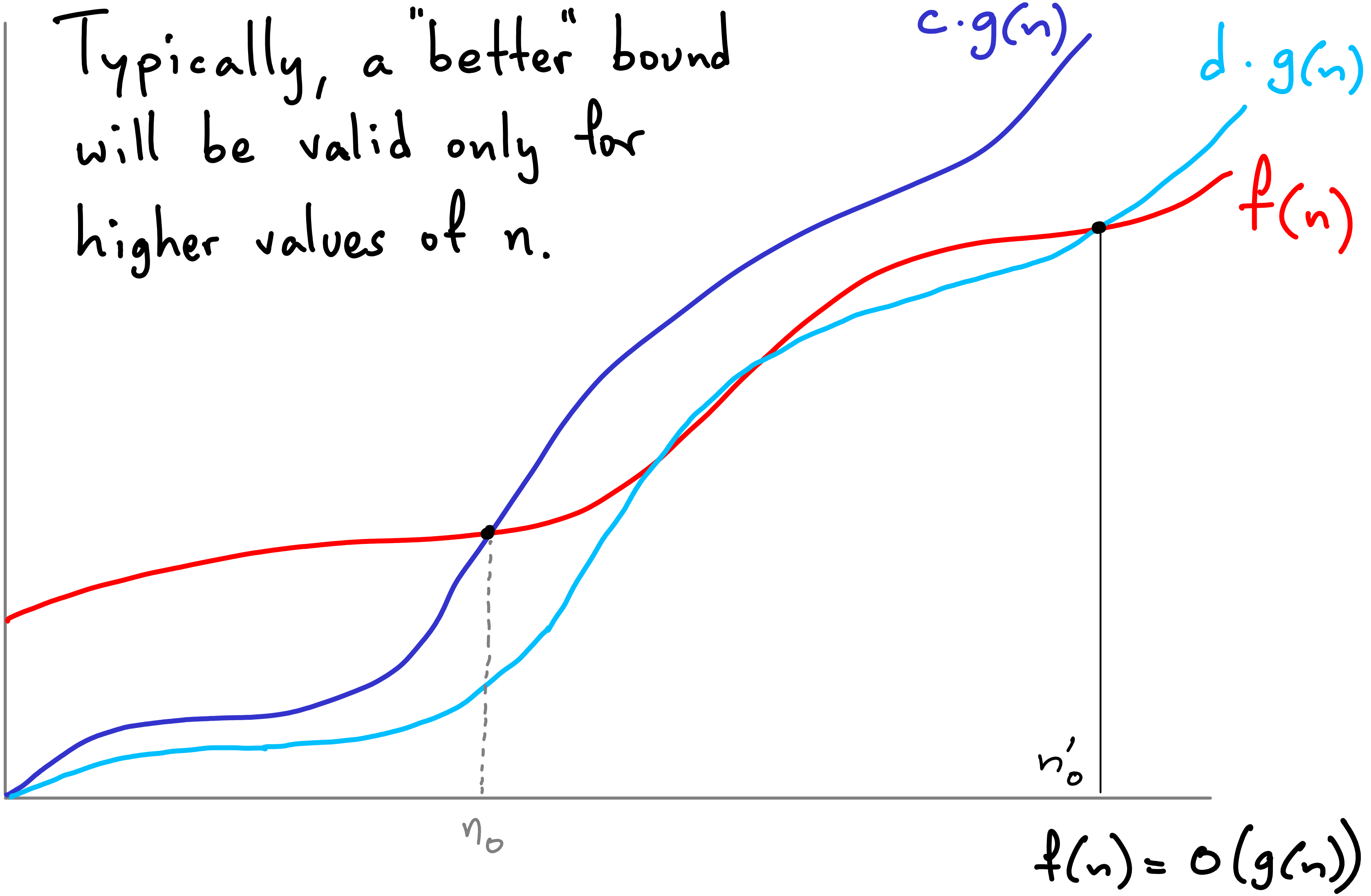
$f(n) = O(g(n))$



$d < c$

$f(n) = o(g(n))$

Typically, a "better" bound will be valid only for higher values of n.



$d < c$

↓

better

Prove $\frac{1}{2}n^2 + 3n - 10 = \Theta(n^2)$

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↳ prove $= O(n^2)$

↳ prove $= \Omega(n^2)$

Prove $\frac{1}{2}n^2 + 3n - 10 = \Theta(n^2)$

$\hookrightarrow$ prove $= O(n^2)$ $\rightarrow$ find c_1 & n_1 s.t. $\frac{1}{2}n^2 + 3n - 10 \leq c_1 \cdot n^2$ for $n > n_1$

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↳ $\frac{1}{2}n^2+3n-10 < 3.5n^2$

(exaggerate & simplify)

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$\frac{1}{2}n^2 + 3n - 10 < 3.5n^2 \Rightarrow c_1 = 3.5$ & $n_1 = 1$ work

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(underestimate & simplify)

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$\frac{1}{2}n^2 + 3n - 10 > \frac{1}{2}n^2 - 10 = \frac{4}{10}n^2 + \left(\frac{1}{10}n^2 - 10\right)$

(underestimate & simplify)

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(exaggerate & simplify)

↳ prove $=\Omega(n^2)$ → find c_2 & n_2 s.t. $\frac{1}{2}n^2+3n-10 \geqslant c_2 \cdot n^2$ for $n > n_2$

$$\frac{1}{2}n^2+3n-10 > \frac{1}{2}n^2-10 = \frac{4}{10}n^2 + \underbrace{\left(\frac{1}{10}n^2-10\right)} > \frac{4}{10}n^2 \quad \text{for } n \geqslant 10$$

(underestimate & simplify)

Prove $\frac{1}{2}n^2 + 3n - 10 = \Theta(n^2)$

↳ prove $= O(n^2)$ → find c_1 & n_1 s.t. $\frac{1}{2}n^2 + 3n - 10 \leq c_1 \cdot n^2$ for $n > n_1$

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↳ prove $= \Omega(n^2)$ → find c_2 & n_2 s.t. $\frac{1}{2}n^2 + 3n - 10 \geq c_2 \cdot n^2$ for $n > n_2$

↳ $\frac{1}{2}n^2 + 3n - 10 > \frac{1}{2}n^2 - 10 = \frac{4}{10}n^2 + \underbrace{\left(\frac{1}{10}n^2 - 10\right)}$

(underestimate & simplify) $> \frac{4}{10}n^2$ for $n \geq 10$

$c_2 = 0.4$ & $n_2 = 10$ work

How NOT to prove $f(n) = \frac{1}{2}n^2 + 3n - 10 = O(n^2)$

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$$\frac{\frac{1}{2}n^2}{n^2} + \frac{3n}{n^2} - \frac{10}{n^2} \leq \frac{cn^2}{n^2}$$

(this step is ok)

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- We need to show $\frac{1}{2}n^2 + 3n - 10 \le cn^2 \ldots$

$$\frac{\frac{1}{2}\cancel{n^2}}{\cancel{n^2}} + \cancel{\frac{3n}{n^2} - \frac{10}{n^2}} \le \frac{c\cancel{n^2}}{\cancel{n^2}} \quad \text{so as } n \to \infty, \ \frac{1}{2} \le c \quad \boxed{\text{NOT OK}}$$

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if it were true, then $c_1 n^2 \leq 6n^3 \leq c_2 n^2$ for $n \geqslant n_0$

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if it were true, then $\underbrace{c_1 n^2 \leq 6n^3}_{\Omega} \leq c_2 n^2$ for $n \geqslant n_0$

$6n^3 \geqslant c_1 \cdot n^2 \rightarrow$ trivially true for $n \geqslant 1$ & $c_1 = 6$

Prove $6n^3 \neq \Theta(n^2)$

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$\boxed{\text{NO}}$

$6n \leq c_2$?

$n \leq \frac{c_2}{6}$ } NO.

Whatever constant c_2 we choose, n will eventually surpass it.

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e.g., $n^3 = \omega(n^2)$ but $5n^2 \neq \omega(n^2)$