

1. Compute

1.  $\sum_{i=0}^n \sum_{k=0}^i 2^k$

$$\begin{aligned} \sum_{i=0}^n \sum_{k=0}^i 2^k &= \sum_{i=0}^n (2^{i+1} - 1) \\ &= \sum_{i=0}^n 2^{i+1} - \sum_{i=0}^n 1 \\ &= 2 \cdot \sum_{i=0}^n 2^i - \sum_{i=0}^n 1 \\ &= 2 \cdot (2^{n+1} - 1) - n \end{aligned}$$

2.  $4^{\log_2(5)} + \log^2(8^3)$

$$\begin{aligned} 4^{\log_2(5)} + \log^2(8^3) &= 2^{\log_2(5^2)} + 3^2 \cdot \log_2^2(8) \\ &= 25 + 3^2 \cdot 3^2 \\ &= 25 + 3^4 \end{aligned}$$

2. Use L'Hopital's rule to determine the limit of:

$$\begin{aligned} \lim_{x \rightarrow \infty} \frac{x \cdot \ln x^5 + 4}{(3 \cdot x + 1)^2} &= \lim_{x \rightarrow \infty} \frac{5 \cdot x \cdot \ln(x) + 4}{9 \cdot x^2 + 6 \cdot x + 1} \\ &= 0 \end{aligned}$$

3. What is the definition of  $f(n) = \Omega(g(n))$ .

$$f(n) = \Omega(g(n)) \iff \exists c > 0, \exists k \geq 0 \text{ s.t. } f(n) \geq c \cdot g(n) \forall n \geq k$$

4. What is the growth of the below function

$$f(n) = n \cdot 2^{\log_2(n)} + \sqrt{n} + 5 \cdot n \cdot \log^3(n) + \log^2(n^n)$$

1.  $\Theta(n^2)$

2.  $\Theta(n \cdot \log^3(n))$

3.  $\Theta(\sqrt{n})$
4.  $\Theta(n^2 \cdot \log^2(n))$
5. Neither!

$$\begin{aligned}
 f(n) &= n \cdot 2^{\log_2(n)} + \sqrt{n} + 5 \cdot n \cdot \log^3(n) + \log^2(n^n) \\
 &= n^2 + \sqrt{n} + 5 \cdot n \cdot \log^3(n) + n^2 \cdot \log^2(n) \\
 &= \Theta(n^2 \cdot \log^2(n))
 \end{aligned}$$

(4) is the correct answer.

5. What is the growth of the below function

$$f(n) = 6 \cdot \log(n) + 4 \cdot \log^4 \log^3(n) + 3 \cdot \log(n^2) + \log^2(n)$$

1.  $\Theta(\log(n))$
2.  $\Theta(\log(n^2))$
3.  $\Theta(\log^4 \log^3(n))$
4.  $\Theta(\log^2(n))$
5. Neither!

$$f(n) = \Theta(\log^2(n))$$

(4) is the correct answer.

8. Prove that  $f(n) = 2 \cdot n \cdot \log(n^2) - 6 \cdot \log^2(n) + \sqrt{n}$  is  $O(n \cdot \log(n))$ , provide the appropriate  $C$  and  $k$  constants.

$$\begin{aligned}
 2 \cdot n \cdot \log(n^2) - 6 \cdot \log^2(n) + \sqrt{n} &= 4 \cdot n \cdot \log(n) - 6 \cdot \log^2(n) + \sqrt{n} \\
 &\leq 4 \cdot n \cdot \log(n) + 6 \cdot n \cdot \log(n) + \sqrt{n} \\
 &\leq 4 \cdot n \cdot \log(n) + 6 \cdot n \cdot \log(n) + n \cdot \log(n) \\
 &= 11 \cdot n \cdot \log(n), n \geq 4
 \end{aligned}$$

Let  $c = 11$  and  $k = 4$  then the statement translates to

$$2 \cdot \log(n^2) - 6 \cdot \log^2(n) + \sqrt{n} \leq c \cdot n \cdot \log(n), n \geq k$$

which by the definition of big- $O$  notation,  $2 \cdot n \cdot \log(n^2) - 6 \cdot \log^2(n) + \sqrt{n}$  is  $O(n \cdot \log(n))$ .

9. Compare the growth of  $f(n) = 4^{2^{\log_2(n)}}$  and  $g(n) = 2^{n+\log(n)}$

$$\begin{aligned} f(n) &= 4^n \\ g(n) &= n \cdot 2^n \end{aligned}$$

$$\begin{aligned} \lim_{n \rightarrow \infty} \frac{2^{2 \cdot n}}{n \cdot 2^n} &= \lim_{n \rightarrow \infty} \frac{2^n}{n} \\ &= \infty \end{aligned}$$

$f(n) = \omega(g(n))$  this implies  $f(n) = \Omega(g(n))$ . We also know then that  $g(n) = O(f(n))$ .

10. Prove transitivity of big- $O$ : if  $f(n) = O(g(n))$ , and  $g(n) = O(h(n))$ , then  $f(n) = O(h(n))$ .

Since  $f(n) = O(g(n))$  and  $g(n) = O(h(n))$  we have the equalities

$$\begin{aligned} f(n) &\leq c_1 \cdot g(n), n \geq k_1 \\ g(n) &\leq c_2 \cdot h(n), n \geq k_2 \end{aligned}$$

From this we obtain

$$f(n) \leq c_1 \cdot c_2 \cdot h(n), n \geq k'$$

where  $k' = \max(k_1, k_2)$ . Let  $c = c_1 \cdot c_2$  and  $k = k'$  the statement then translate to

$$f(n) \leq c \cdot h(n), n \geq k$$

which by the definition of  $O$  notation,  $f(n) = O(h(n))$ .

11. What is the growth of  $n^2 + 2 \cdot n^2 + 3 \cdot n^2 + 4 \cdot n^2 + \dots + n^5$ ?

$$\begin{aligned} \sum_{i=1}^{n^3} i \cdot n^2 &= n^2 \cdot \sum_{i=1}^{n^3} i \\ &= n^2 \cdot \frac{(n^3) \cdot (n^3 + 1)}{2} \\ &= \frac{n^8 + n^5}{2} \\ &= \Theta(n^8) \end{aligned}$$

**12.** Prove  $\forall k > 0, \epsilon > 0 \implies \log^k(n) = o(n^\epsilon)$ .

We prove this by induction on  $k$ , let  $\epsilon$  be a real number greater than 0. When  $k = 1$  we have

$$\begin{aligned} \lim_{n \rightarrow \infty} \frac{\log(n)}{n^\epsilon} &= \lim_{n \rightarrow \infty} \frac{\frac{1}{n \cdot \ln(2)}}{\epsilon \cdot n^{\epsilon-1}} \\ &= \lim_{n \rightarrow \infty} \frac{1}{\epsilon \cdot \ln(2) \cdot n^\epsilon} \\ &= 0 \end{aligned}$$

Assume that the result holds for all  $n$  greater than or equal to some integer  $k$ , we show it must also hold for the  $k + 1$  integer.

$$\begin{aligned} \lim_{n \rightarrow \infty} \frac{\log^{k+1}(n)}{n^\epsilon} &= \lim_{n \rightarrow \infty} \frac{(k+1) \cdot \log^k(n) \cdot \frac{1}{n \cdot \ln(2)}}{\epsilon \cdot n^{\epsilon-1}} \\ &= \lim_{n \rightarrow \infty} \frac{(k+1) \cdot \log^k(n)}{\epsilon \cdot \ln(2) \cdot n^\epsilon} \\ &= 0 \end{aligned}$$

which is what we wanted to show. Hence by the principle of mathematical induction the result holds for all  $n > 0$  and  $\epsilon > 0$ .

**13.** Use to the definition of big- $O$  to prove that  $f(n) + g(n) = O(\max(f(n), g(n)))$ .

$$f(n) + g(n) \leq 2 \cdot \max(f(n), g(n)), n \geq 1$$

which by the definition of big- $O$  notation,  $f(n) + g(n) = O(\max(f(n), g(n)))$ .

**14.** Prove or disprove  $(n!)^{\log(n)} = \omega(n^{2^{\log(n)}})$

$$\begin{aligned} \log(\lim_{n \rightarrow \infty} \frac{n!^{\log(n)}}{n^n}) &= \lim_{n \rightarrow \infty} \log(n) \cdot \log(n!) - n \cdot \log(n) \\ &= \lim_{n \rightarrow \infty} \log(n) \cdot \sum_{i=0}^n \log(n) - n \cdot \log(n) \\ &= \lim_{n \rightarrow \infty} \log(n) \cdot \sum_{i=0}^{n-1} \log(n) \\ &= \infty \\ 2^{\log(\lim_{n \rightarrow \infty} \frac{n!^{\log(n)}}{n^n})} &= 2^\infty \\ &= \infty \end{aligned}$$

which by the definition of little- $\omega$  notation,  $n!^{\log(n)} = \omega(n^{2^{\log(n)}})$ .