Little o notation pdf

Big O little o . ., Big O ... . 'f(x) g(x) Big O' ., f(x) x가 ∞ 가 g(x) . . '가' , x0 가 .M , 가 Big O notation . , Big O .3x x2 Big O. .x가 ,3 x2 3x . Big O. Big O x가 , xk 가 Big O . little o . . Big O x가 가 ,Little O x가 Big O . , .g(x) f(x) x 가 . , ' ' 가 ., Little o Big O .Little o g(x)가 0 , . , 3x가 x2x가 가 x2 0.5 , 0.1 ... 3x x . x2 가 x ., little o . Notation describing limiting behavior Example of Big O notation: f (x) ∈ O (g (x)) {\displaystyle {\color {red}f(x)}\in O{\color {blue}(g(x))}} as there exists M > 0 {\displaystyle M>0} (e.g., M = 1 {\displaystyle M=1}) and x 0 {\displaystyle x_{0}} (e.g., x 0 = 5 {\displaystyle x_{0}=5}) such that f (x) ≤ M g (x) {\displaystyle {\color {red}f(x)}\leq {\color {blue}Mg(x)}} whenever x ≥ x 0 {\displaystyle x\geq x_{0}} . Fit approximation Concepts Orders of approximationScale analysis · Big O notationCurve fitting · False precisionSignificant figures Other fundamentals Approximation · Generalization errorTaylor polynomialScientific modelling vte Big O notation is a mathematical notation that describes the limiting behavior of a function when the argument tends towards a particular value or infinity. Big O is a member of a family of notations invented by Paul Bachmann,[1] Edmund Landau,[2] and others, collectively called Bachmann–Landau notation or asymptotic notation. The letter O was chosen by Bachmann to stand for Ordnung, meaning the order of approximation. In computer science, big O notation is used to classify algorithms according to how their run time or space requirements grow as the input size grows.[3] In analytic number theory, big O notation is often used to express a bound on the difference between an arithmetical function and a better understood approximation; a famous example of such a difference is the remainder term in the prime number theorem. Big O notation is also used in many other fields to provide similar estimates. Big O notation characterizes functions according to their growth rates: different functions with the same growth rate may be represented using the same O notation. The letter O is used because the growth rate of a function is also referred to as the order of the function. A description of a function in terms of big O notation usually only provides an upper bound on the growth rate of the function. Associated with big O notation are several related notations, using the symbols o, Ω, ω, and Θ, to describe other kinds of bounds on asymptotic growth rates. Formal definition Let f {\displaystyle f} , the function to be estimated, be a real or complex valued function and let g {\displaystyle g} , the comparison function, be a real valued function. Let both functions be defined on some unbounded subset of the positive real numbers, and g (x) {\displaystyle g(x)} be strictly positive for all large enough values of x {\displaystyle x} .[4] One writes f (x) = O (g (x)) as x → ∞ {\displaystyle f(x)=O{\bigl (}g(x){\bigr)}\quad {\text{ as }}x\to \infty } if the absolute value of f (x) {\displaystyle f(x)} is at most a positive constant multiple of g (x) {\displaystyle g(x)} for all sufficiently large values of x {\displaystyle x} . That is, f (x) = O (g (x)) {\displaystyle f(x)=O{\bigl (}g(x){\bigr)}} if there exists a positive real number M {\displaystyle M} and a real number x 0 {\displaystyle x_{0}} such that | f (x) | ≤ M g (x) for all x ≥ x 0 . {\displaystyle |f(x)|\leq Mg(x)\quad {\text{ for all }}x\geq x_{0}.} In many contexts, the assumption that we are interested in the growth rate as the variable x {\displaystyle x} goes to infinity is left unstated, and one writes more simply that f (x) = O (g (x)) . {\displaystyle f(x)=O{\bigl (}g(x){\bigr)}.} The notation can also be used to describe the behavior of f {\displaystyle f} near some real number a {\displaystyle a} (often, a = 0 {\displaystyle a=0}): we say f (x) = O (g (x)) as x → a {\displaystyle f(x)=O{\bigl (}g(x){\bigr)}\quad {\text{ as }}x\to a} if there exist positive numbers δ {\displaystyle \delta } and M {\displaystyle M} such that for all defined x {\displaystyle x} with 0 < | x − a | < δ {\displaystyle 0 0 {\displaystyle C>0} such that | f (x) | ≤ C | g (x) | {\displaystyle |f(\mathbf {x})|\leq C|g(\mathbf {x})|} for all x {\displaystyle \mathbf {x} } with x i ≥ M {\displaystyle x_{i}\geq M} for some i . {\displaystyle i.} [7] Equivalently, the condition that x i ≥ M {\displaystyle x_{i}\geq M} for some i {\displaystyle i} can be written ‖ x ‖ ∞ ≥ M {\displaystyle \|\mathbf {x} \|_{\infty }\geq M} , where ‖ x ‖ ∞ {\displaystyle \|\mathbf {x} \|_{\infty }} denotes the Chebyshev norm. For example, the statement f (n , m) = n 2 + m 3 + O (n + m) as n , m → ∞ {\displaystyle f(n,m)=n^{2}+m^{3}+O(n+m)\quad {\text{ as }}n,m\to \infty } asserts that there exist constants C and M such that | f (n , m) − (n 2 + m 3) | ≤ C | n + m | {\displaystyle |f(n,m)-(n^{2}+m^{3})|\leq C|n+m|} whenever either m ≥ M {\displaystyle m\geq M} or n ≥ M {\displaystyle n\geq M} holds. This definition allows all of the coordinates of x {\displaystyle \mathbf {x} } to increase to infinity. In particular, the statement f (n , m) = O (n m) as n , m → ∞ {\displaystyle f(n,m)=O(n^{m})\quad {\text{ as }}n,m\to \infty } (i.e., ∃ C ∃ M ∀ n ∀ m ⋯ {\displaystyle \exists C\,\exists M\,\forall n\,\forall m\,\cdots }) is quite different from ∀ m : f (n , m) = O (n m) as n → ∞ {\displaystyle \forall m\colon ~f(n,m)=O(n^{m})\quad {\text{ as }}n\to \infty } (i.e., ∀ m ∃ C ∃ M ∀ n ⋯ {\displaystyle \forall m\,\exists C\,\exists M\,\forall n\,\cdots }). Under this definition, the subset on which a function is defined is significant when generalizing statements from the univariate setting to the multivariate setting. For example, if f (n , m) = 1 {\displaystyle f(n,m)=1} and g (n , m) = n {\displaystyle g(n,m)=n} , then f (n , m) = O (g (n , m)) {\displaystyle f(n,m)=O(g(n,m))} if we restrict f {\displaystyle f} and g {\displaystyle g} to [1 , ∞) 2 {\displaystyle [1,\infty)^{2}} , but not if they are defined on [0 , ∞) 2 {\displaystyle [0,\infty)^{2}} . This is not the only generalization of big O to multivariate functions, and in practice, there is some inconsistency in the choice of definition.[8] Matters of notation Equals sign The statement "f(x) is O(g(x))" as defined above is usually written as f(x) = O(g(x)). Some consider this to be an abuse of notation, since the use of the equals sign could be misleading as it suggests a symmetry that this statement does not have. As de Bruijn says, O(x) = O(x2) is true but O(x2) = O(x) is not.[9] Knuth describes such statements as "one-way equalities", since if the sides could be reversed, "we could deduce ridiculous things like n = n2 from the identities n = O(n2) and n2 = O(n2)."[10] In another letter, Knuth also pointed out that "the equality sign is not symmetric with respect to such notations", as, in this notation, "mathematicians customarily use the = sign as they use the word "is" in English: Aristotle is a man, but a man isn't necessarily Aristotle".[11] For these reasons, it would be more precise to use set notation and write f(x) ∈ O(g(x)) (read as: "f(x) is an element of O(g(x))", or "f(x) is in the set O(g(x))"), thinking of O(g(x)) as the class of all functions h(x) such that |h(x)| ≤ C|g(x)| for some constant C.[10] However, the use of the equals sign is customary.[9][10] Other arithmetic operators Big O notation can also be used in conjunction with other arithmetic operators in more complicated equations. For example, h(x) + O(f(x)) denotes the collection of functions having the growth of h(x) plus a part whose growth is limited to that of f(x). Thus, g (x) = h (x) + O (f (x)) {\displaystyle g(x)=h(x)+O(f(x))} expresses the same as g (x) − h (x) = O (f (x)) . {\displaystyle g(x)-h(x)=O(f(x)).} Example Suppose an algorithm is being developed to operate on a set of n elements. Its developers are interested in finding a function T(n) that will express how long the algorithm will take to run (in some arbitrary measurement of time) in terms of the number of elements in the input set. The algorithm works by first calling a subroutine to sort the elements in the set and then perform its own operations. The sort has a known time complexity of O(n2), and after the subroutine runs the algorithm must take an additional 55n3 + 2n + 10 steps before it terminates. Thus the overall time complexity of the algorithm can be expressed as T(n) = 55n3 + O(n2). Here the terms 2n + 10 are subsumed within the faster-growing O(n2). Again, this usage disregards some of the formal meaning of the "=" symbol, but it does allow one to use the big O notation as a kind of convenient placeholder. Multiple uses In more complicated usage, O(·) can appear in different places in an equation, even several times on each side. For example, the following are true for n → ∞ {\displaystyle n\to \infty } : (n + 1) 2 = n 2 + O (n) , (n + O (n 1 / 2)) ⋅ (n + O (log n)) 2 = n 3 + O (n 5 / 2) , n O (1) = O (e n) . {\displaystyle {\begin{aligned}(n+1)^{2}&=n^{2}+O(n),\\(n+O(n^{1/2}))\cdot (n+O(\log n))^{2}&=n^{3}+O(n^{5/2}),\\n^{O(1)}&=O(e^{n}).\end{aligned}}} The meaning of such statements is as follows: for any functions which satisfy each O(·) on the left side, there are some functions satisfying each O(·) on the right side, such that substituting all these functions into the equation makes the two sides equal. For example, the third equation above means: "For any function f(n) = O(1), there is some function g(n) = O(en) such that nf(n) = g(n)." In terms of the "set notation" above, the meaning is that the class of functions represented by the left side is a subset of the class of functions represented by the right side. In this use the "=" is a formal symbol that unlike the usual use of "=" is not a symmetric relation. Thus for example nO(1) = O(en) does not imply the false statement O(en) = nO(1). Typesetting Big O is typeset as an italicized uppercase "O", as in the following example: O (n 2) {\displaystyle O(n^{2})} .[12][13] In TeX, it is produced by simply typing O inside math mode. Unlike Greek-named Bachmann–Landau notations, it needs no special symbol. Yet, some authors use the calligraphic variant O {\displaystyle {\mathcal {O}}} instead.[14][15] Orders of common functions Further information: Time complexity § Table of common time complexities Here is a list of classes of functions that are commonly encountered when analyzing the running time of an algorithm. In each case, c is a positive constant and n increases without bound. The slower-growing functions are generally listed first. Notation Name Example O (1) {\displaystyle O(1)} constant Determining if a binary number is even or odd; Calculating (− 1) n {\displaystyle (-1)^{n}} ; Using a constant-size lookup table O (log log n) {\displaystyle O(\log \log n)} double logarithmic Average number of comparisons spent finding an item using interpolation search in a sorted array of uniformly distributed values O (log n) {\displaystyle O(\log n)} logarithmic Finding an item in a sorted array with a binary search or a balanced search tree as well as all operations in a binomial heap O ((log n) c) {\displaystyle O((\log n)^{c})} c > 1 {\textstyle c>1} polylogarithmic Matrix chain ordering can be solved in polylogarithmic time on a parallel random-access machine. O (n c) {\displaystyle O(n^{c})} 0 < c < 1 {\textstyle 0

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