

# Homework 2 of Computational Mathematics

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1.  $x^3 = x + 1 \implies x^2 = 1 + \frac{1}{x} \implies x = \sqrt{1 + \frac{1}{x}} = g(x)$ .  $p_1 = g(p_0) = \sqrt{1+1} = \sqrt{2} \approx 1.414$ .  $p_2 = g(p_1) = \sqrt{1 + \frac{1}{\sqrt{2}}} \approx 1.3065$ .  $p_3 = g(p_2) \approx 1.3172$ .  $p_4 = g(p_3) \approx 1.326$ .  $p_5 = g(p_4) \approx 1.324$ . Then,  $p_4$  is the answer that we want to find.

2. Let  $f(x) = x^3 + x - 4$ ,  $f'(x) = 3x^2 + 1 < 49$  for all  $x \in [1, 4]$ . Thus, for  $|x - y| < \frac{10^{-3}}{49} \approx 2.0409e-5$ ,  $|f(x) - f(y)| < 10^3$ . Find  $n$  s.t.  $3 \cdot 2^{-n} < 2.0409e-5$ ,  $n > -\log_2\left(\frac{2.0409e-5}{3}\right) \approx 17.1653$ . Thus, the bound of the number of iteration is 18. Then, by python code below, the root is about 1.3787.

```
HW2 > HW2.py > ...
1  a = [1]
2  b = [4]
3
4  def f(x):
5      return x**3 + x - 4
6
7  while 1:
8      mid = (a[-1] + b[-1])/2
9      val = f(mid)
10     print(mid, val)
11
12     if abs(val) < 0.0001:
13         break
14     elif val > 0:
15         b.append(mid)
16     else:
17         a.append(mid)

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS
PS C:\Users\ryan\OneDrive - 國立陽明交通大學\HW\計數> &
2.5 14.125
1.75 3.109375
1.375 -0.025390625
1.5625 1.377197265625
1.46875 0.637176513671875
1.421875 0.2965202331542969
1.3984375 0.13326025009155273
1.38671875 0.05336350202560425
1.380859375 0.013844214379787445
1.3779296875 -0.005808685906231403
1.37939453125 0.004008884658105671
1.378662109375 -0.0009021193400258198
1.3790283203125 0.0015528278327110456
1.37884521484375 0.00032521555817766057
1.378753662109375 -0.00028848656066315925
1.3787994384765625 1.8355831034710945e-05
```

3. In this question, we let  $p_{n+1} = g(p_n)$  and  $p = \sqrt[3]{21}$ . And by  $\lim_{n \rightarrow \infty} \frac{|p_{n+1} - p|}{|p_n - p|^\alpha} = \lambda$ ,

$$\frac{|p_{n+1} - p|}{|p_n - p|} \approx \frac{\lambda |p_n - p|^\alpha}{\lambda |p_{n-1} - p|^\alpha} \approx \left| \frac{p_n - p}{p_{n-1} - p} \right|^\alpha, \text{ then } \alpha \approx \frac{\ln |(p_{n+1} - p)/(p_n - p)|}{\ln |(p_n - p)/(p_{n-1} - p)|}.$$

Then, by observing the function, we get  $b$  is quadratic convergence (Newton's method). In the meanwhile, though  $\sqrt[3]{21}$  is a fixed point of  $c$ , but it will diverges or converges to 0 for any open interval contains  $\sqrt[3]{21}$ .

Thus, by result of iteration with python below, the order of speed of convergence is  $b > d > a$ .

```

20
21 def problem_3():
22     import math
23     p = 21**(1.0/3)
24     def a(x):
25         return (20*(x**3)+21)/(21*(x**2))
26
27     def b(x):
28         return x- (x**3 - 21)/(3*(x**2))
29
30     def c(x):
31         return x - (x**4 - 21*x)/(x**2 - 21)
32
33     def d(x):
34         return math.sqrt(21/x)
35
36     def Alpha(f, x):
37         return math.log(abs((f(x) - p)/(x - p)))
38
39     functions = {"a": a, "b": b, "c":c, "d": d}
40
41     for i in functions.keys():
42         f = functions[i]
43         p_now = 1
44         for k in range(20):
45             p_now = f(p_now)
46             # print(k+1, "err:", abs(p_now - p))
47         try:
48             alpha = Alpha(f, f(p_now))/Alpha(f, p_now)
49             print(i, alpha)
50         except:
51             print(i, "Cannot compute alpha by this method.")
52
53     print("----")
54
55 def problem_4():
56     def a(x):

```

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS

```

PS C:\Users\9ryan\OneDrive - 國立陽明交通大學\HW\計數> & C:/Users/9ryan/AppD
a 0.9982564193669963
---
b Cannot compute alpha by this method.
---
c Cannot compute alpha by this method.
---
d 1.0000015723442375
---
PS C:\Users\9ryan\OneDrive - 國立陽明交通大學\HW\計數>

```

4.  $|g'(x)| = |-2^{-x} \ln(2)|$  is continuous and decreasing on  $\mathbb{R}$ . Thus,  $g'(\frac{1}{3}) \approx 0.55015$ . And since  $g(\frac{1}{3}) \approx 0.79370 > \frac{1}{3}$  and  $g(1) = \frac{1}{2} < 1$ . By Theorem 2.3,  $g(x)$  has unique fixed point on  $[\frac{1}{3}, 1]$ .

```

54
55 def problem_4():
56     def g(x):
57         return 2*(-x)
58
59     x = 0.3334
60     step = 0
61     while abs(x-g(x)) >= 10**(-4):
62         x = g(x)
63         step += 1
64         print("step:", step, ",value:", x)
65
66
67 if __name__ == "__main__":
68     problem_4()

```

PROBLEMS OUTPUT DEBUG CONSOLE **TERMINAL** PORTS

```

step: 1 ,value: 0.79366385007938
step: 2 ,value: 0.5768772000497738
step: 3 ,value: 0.6704133579003061
step: 4 ,value: 0.6283266346632733
step: 5 ,value: 0.6469263427213542
step: 6 ,value: 0.6386394847182052
step: 7 ,value: 0.6423183934819865
step: 8 ,value: 0.6406825519733249
step: 9 ,value: 0.6414094204320899
step: 10 ,value: 0.6410863425561439
step: 11 ,value: 0.6412299238405336

```

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By the result from python above, we need 12 steps to let error less than  $10^{-4}$ . Since  $|g'(x)| \leq \ln(2)2^{-x} \leq 0.551$ , we take  $k = 0.551$  and  $p_0 = 1$ .  $|p_n - p| \leq \frac{k^n}{1-k} |p_1 - p| \approx k^n \cdot 1.113585746 \leq 10^{-4}$ . Then,  $n \geq 15.633566$ , that is, the bound is 16 times of iteration.

5. (a) Let  $x_*$  be nonzero fixed point of  $g$ ,  $x_* = 2x_* - Ax_*^2 \implies x_* = Ax_*^2 \implies x_*^*A = 1$ . Thus,  $x_* = \frac{1}{A}$ .  
 (b) Since  $g'(x) = 2 - 2Ax$  and we need  $|g'(x)| < k < 1$ ,

$$\begin{aligned}
 |2 - 2Ax| < k &\iff -k < 2 - 2Ax < k \\
 &\iff \frac{k-2}{2A} < x < \frac{k+2}{2A} \\
 &\stackrel{k=1-\epsilon}{\iff} \frac{1}{2A} + \frac{\epsilon}{2A} < x < \frac{3}{2A} - \frac{\epsilon}{2A}
 \end{aligned}$$

$$\text{Thus, } x \in \left( \frac{1}{2A} + \frac{\epsilon}{2A}, \frac{3}{2A} - \frac{\epsilon}{2A} \right).$$

6. Let  $g(x) = \frac{x}{2} + \frac{A}{2x}$ , and  $g'(x) = \frac{1}{2} - \frac{A}{2x^2}$ . For  $x \in (\sqrt{A}, \infty)$ ,  $|g'(x)| \leq \frac{1}{2}$ . And since  $x > \sqrt{A}$ ,  $\frac{x}{2} + \frac{A}{2x} - \sqrt{A} = \frac{x^2 + A - 2Ax}{2x} = \frac{(x - \sqrt{A})^2}{2x} > 0$ . Thus, if  $x > \sqrt{A}$ ,  $g(x) > \sqrt{A}$ . By Corollary 2.5,  $g(x)$  converges to  $\sqrt{A}$  for all  $(\sqrt{A}, \infty)$ .

Then, for  $x \in (0, \sqrt{A})$ ,  $\frac{x}{2} + \frac{A}{2x} - \sqrt{A} = \frac{(A-x)^2}{2x} > 0$ . Thus, for  $0 < x < \sqrt{A}$ ,  $g(x) > \sqrt{A}$ , and then by the argument above, it will converge to  $\sqrt{A}$ , too.

Therefore, for  $x_0 > 0$ ,  $x_n$  will converge to  $\sqrt{A}$ .

$$7. \quad (a) \quad p_2 = p_1 - \frac{f(p_1)[p_0 - p_1]}{f(p_0) - f(p_1)} = -\frac{-1}{-1 + \cos(-1) - 1} = \frac{1}{-2 + \cos(1)} \approx -0.6850733573260451.$$

$$p_3 = p_2 - \frac{f(p_2)[p_1 - p_2]}{f(p_1) - f(p_2)} \approx -1.252076488909229.$$

$$(b) \quad p_2 = p_1 - f(p_1) \cdot \frac{p_0 - p_1}{f(p_0) - f(p_1)} \approx -0.6850733573260451. \text{ Since } f(p_2) < 0, f(p_2) \cdot f(p_0) < 0.$$

$$\text{Then, } p_3 = p_2 - f(p_2) \cdot \frac{p_0 - p_2}{f(p_0) - f(p_2)} \approx -0.8413551256656522.$$

8.