https://doi.org/10.17221/139/2024-SWR

Approximation of the soil particle-size distribution curve using a NURBS curve

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Electronic Supplementary Material (ESM)

The authors are fully responsible for both the content and the formal aspects of the electronic supplementary material. No editorial adjustments were made.

https://doi.org/10.17221/139/2024-SWR

Supplementary Material 1.

Algorithm for calculation of basis B-spline functions in PL/SQL (Oracle database procedural language)

For:

- parametrization vector *u*
- the order of the curve *k, kk*
- the index of the basis function *i*
- independent variable *t*

```
FUNCTION basis_fn (     kk          IN      PLS_INTEGER,
                        k           IN      PLS_INTEGER,
                        i           IN      PLS_INTEGER,
                        t           IN      NUMBER) RETURN NUMBER IS
        res     NUMBER;
        l1      NUMBER;
        l2      NUMBER;
BEGIN
        IF u.count > 0 THEN
                CASE
                WHEN k = 1 THEN
                        res := CASE
                                WHEN (i+1) < (u.count - kk) and t >= u (i) AND t < u (i + 1) THEN 1 WHEN (i+1)
                                = (u.count - kk) and t >= u (i) AND t <= u (i + 1) THEN 1
                                ELSE 0 END;
                ELSE
                        l1 := CASE
                                WHEN u (i + k - 1) = u (i) THEN 0
                                ELSE ((t - u (i)) / (u (i + k - 1) - u (i))) * basis_fn (kk, k - 1, i, t)
                                END;
                        l2 := CASE
                                WHEN u (i + k) = u (i + 1) THEN 0
                                ELSE ((u (i + k) - t) / (  u (i + k) - u (i + 1))) * basis_fn (kk, k - 1, i + 1, t) END;
                        res := l1 + l2;
                END CASE;
        END IF;

        RETURN res;
END;
```

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Table S1. Example 1 – Points of the resulting approximation curves with the uniform nodal vector of parametrization – A particle size distribution curve (d – particle size; p – percentage of fraction)

3rd degree curve		2nd degree curve		1st degree curve	
d (mm)	cumulative p (%)	d (mm)	cumulative p (%)	d (mm)	cumulative p (%)
0.0010	45.40	0.0010	45.40	0.0010	45.40
0.0031	59.83	0.0032	60.38	0.0023	56.85
0.0052	66.00	0.0056	67.10	0.0038	63.55
0.0073	69.51	0.0079	70.96	0.0054	68.31
0.0093	71.79	0.0102	73.43	0.0070	71.99
0.0112	73.40	0.0123	75.11	0.0088	75.01
0.0129	74.60	0.0142	76.29	0.0104	76.90
0.0146	75.53	0.0160	77.14	0.0116	77.18
0.0161	76.27	0.0176	77.75	0.0129	77.43
0.0176	76.88	0.0191	78.19	0.0141	77.65
0.0296	79.79	0.0300	79.60	0.0253	79.11
0.0387	80.92	0.0388	80.43	0.0357	79.96
0.0466	81.63	0.0466	81.08	0.0455	80.57
0.0537	82.18	0.0537	81.63	0.0550	81.29
0.0603	82.64	0.0603	82.1	0.0641	82.10
0.0666	83.05	0.0665	82.52	0.0731	82.78
0.0727	83.42	0.0723	82.89	0.0818	83.37
0.0786	83.76	0.0780	83.23	0.0904	83.89
0.0844	84.07	0.0834	83.54	0.0988	84.36
0.1400	86.41	0.1309	85.82	0.1778	87.42
0.1679	87.30	0.1554	86.72	0.2148	88.41
0.1966	88.08	0.1815	87.53	0.2509	89.22
0.2567	89.41	0.2383	88.94	0.3437	90.85
0.3213	90.55	0.3010	90.16	0.4387	92.12
0.3907	91.55	0.3696	91.23	0.5356	93.16
0.4653	92.44	0.4443	92.18	0.6340	94.03
0.5453	93.26	0.5251	93.05	0.7338	94.79
0.6309	94.02	0.6120	93.85	0.8347	95.46
0.7224	94.72	0.7052	94.58	0.9367	96.06
0.8199	95.37	0.8048	95.27	1.0397	96.60
0.9237	95.99	0.9107	95.91	1.1436	97.10
1.0339	96.57	1.0231	96.52	1.2482	97.55
1.1506	97.13	1.1422	97.09	1.3537	97.97
1.2742	97.66	1.2679	97.63	1.4598	98.36
1.4047	98.16	1.4004	98.15	1.5667	98.73
1.5423	98.65	1.5398	98.64	1.6741	99.08
1.6873	99.12	1.6861	99.11	1.7822	99.40
1.8398	99.57	1.8395	99.57	1.8908	99.71
2.0000	100.00	2.0000	100.00	2.0000	100.00

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Table S2. Example 2 – Points of the resulting approximation curves with the non-uniform nodal vector of parametrization determined by the center of gravity method – A particle size distribution curve (d – particle size; p – percentage of fraction)

3rd degree curve		2nd degree curve		1st degree curve	
d (mm)	cumulative p (%)	d (mm)	cumulative p (%)	d (mm)	cumulative p (%)
0.0010	45.40	0.0010	45.40	0.0010	45.40
0.0026	57.73	0.0022	55.79	0.0017	52.43
0.0042	63.37	0.0034	61.00	0.0023	56.54
0.0058	66.74	0.0045	64.31	0.0028	59.46
0.0073	69.04	0.0055	66.65	0.0033	61.72
0.0087	70.72	0.0066	68.42	0.0038	63.57
0.0101	72.02	0.0075	69.82	0.0043	65.14
0.0114	73.05	0.0084	70.96	0.0047	66.49
0.0126	73.90	0.0093	71.90	0.0051	67.69
0.0138	74.62	0.0102	72.70	0.0055	68.75
0.0240	78.33	0.0172	76.89	0.0093	75.78
0.0320	79.89	0.0225	78.47	0.0127	77.40
0.0390	80.81	0.0268	79.21	0.0160	77.97
0.0451	81.45	0.0305	79.57	0.0191	78.41
0.0508	81.94	0.0339	79.87	0.0221	78.77
0.0561	82.35	0.0373	80.17	0.0249	79.07
0.0611	82.69	0.0406	80.46	0.0277	79.33
0.0659	82.99	0.0438	80.74	0.0304	79.56
0.0704	83.27	0.0470	81.00	0.0331	79.77
0.1114	85.29	0.0781	83.21	0.0645	82.13
0.1315	86.07	0.0935	84.09	0.0900	83.87
0.1521	86.78	0.1089	84.86	0.1181	85.29
0.1963	88.04	0.1425	86.27	0.1813	87.52
0.2453	89.16	0.1832	87.57	0.2529	89.26
0.2999	90.18	0.2311	88.78	0.3320	90.67
0.3607	91.13	0.2868	89.91	0.4178	91.87
0.4284	92.01	0.3508	90.95	0.5099	92.90
0.5035	92.85	0.4236	91.94	0.6078	93.81
0.5866	93.64	0.5059	92.86	0.7112	94.63
0.6783	94.39	0.5983	93.73	0.8199	95.37
0.7792	95.11	0.7015	94.56	0.9335	96.04
0.8899	95.80	0.8161	95.34	1.0519	96.66
1.0112	96.46	0.9428	96.09	1.1748	97.24
1.1436	97.10	1.0824	96.81	1.3022	97.77
1.2880	97.71	1.2356	97.50	1.4338	98.27
1.4450	98.31	1.4031	98.16	1.5695	98.74
1.6155	98.89	1.5858	98.79	1.7091	99.18
1.8002	99.45	1.7845	99.41	1.8527	99.60
2.0000	100.00	2.0000	100.00	2.0000	100.00

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Table S3. Example 3 – Points of the resulting approximation curves with the uniform nodal vector of parametrization evaluated using particle-size distribution curve with embedded intermediate values by linear interpolation – A particle size distribution curve (d – particle size; p – percentage of fraction)

3rd degree curve		2nd degree curve		1st degree curve	
d (mm)	cumulative p (%)	d (mm)	cumulative p (%)	d (mm)	cumulative p (%)
0.0010	45.40	0.0010	45.40	0.0010	45.40
0.0036	62.75	0.0029	59.82	0.0017	52.76
0.0066	70.82	0.0057	69.18	0.0032	61.46
0.0084	73.69	0.0074	72.74	0.0052	67.91
0.0095	74.99	0.0085	74.38	0.0067	71.32
0.0104	75.78	0.0093	75.35	0.0078	73.47
0.0112	76.31	0.0100	76.00	0.0087	74.98
0.0119	76.71	0.0105	76.45	0.0095	76.10
0.0127	77.02	0.0111	76.79	0.0101	76.82
0.0134	77.28	0.0116	77.05	0.0105	76.93
0.0216	78.71	0.0188	78.37	0.0164	78.02
0.0294	79.48	0.0282	79.38	0.0270	79.27
0.0352	79.95	0.0357	79.96	0.0353	79.94
0.0394	80.26	0.0405	80.28	0.0410	80.30
0.0426	80.48	0.0440	80.52	0.0451	80.54
0.0451	80.66	0.0467	80.71	0.0482	80.71
0.0472	80.81	0.0491	80.89	0.0507	80.88
0.0490	80.95	0.0512	81.05	0.0532	81.13
0.0507	81.08	0.0532	81.21	0.0558	81.38
0.0670	82.36	0.0766	83.03	0.0940	84.10
0.0769	83.06	0.0935	84.06	0.1268	85.66
0.0881	83.76	0.1122	85.02	0.1547	86.70
0.1132	85.06	0.1485	86.48	0.1936	87.87
0.1391	86.14	0.1774	87.41	0.2197	88.53
0.1660	87.06	0.1990	88.01	0.2387	88.96
0.1960	87.93	0.2278	88.71	0.2679	89.56
0.2306	88.77	0.2660	89.52	0.3459	90.89
0.2714	89.62	0.3136	90.38	0.4334	92.06
0.3199	90.48	0.3714	91.25	0.5303	93.11
0.3781	91.35	0.4406	92.14	0.6365	94.05
0.4481	92.23	0.5228	93.03	0.7519	94.92
0.5329	93.13	0.6203	93.92	0.8765	95.72
0.6358	94.05	0.7353	94.80	1.0101	96.45
0.7614	94.98	0.8708	95.68	1.1528	97.14
0.9155	95.94	1.0303	96.55	1.3045	97.78
1.1053	96.92	1.2178	97.42	1.4651	98.38
1.3404	97.92	1.4380	98.29	1.6346	98.95
1.6332	98.95	1.6966	99.15	1.8129	99.49
2.0000	100.00	2.0000	100.00	2.0000	100.00

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Table S4. Example 4 – Points of the resulting approximation curves with the non-uniform nodal vector of parametrization determined by the center of gravity method evaluated using particle-size distribution curve with embedded intermediate values by linear interpolation – A particle size distribution curve (d – particle size; p – percentage of fraction)

3rd degree curve		2nd degree curve		1st degree curve	
d (mm)	cumulative p (%)	d (mm)	cumulative p (%)	d (mm)	cumulative p (%)
0.0010	45.40	0.0010	45.40	0.0010	45.40
0.0018	53.19	0.0015	50.89	0.0012	48.36
0.0028	59.27	0.0021	55.53	0.0015	50.68
0.0038	63.44	0.0028	59.25	0.0017	52.71
0.0048	66.35	0.0034	62.20	0.0020	54.57
0.0056	68.44	0.0041	64.56	0.0022	56.34
0.0064	70.00	0.0047	66.45	0.0025	58.04
0.0070	71.18	0.0052	67.99	0.0029	59.69
0.0076	72.12	0.0057	69.24	0.0032	61.41
0.0081	72.86	0.0062	70.28	0.0037	63.37
0.0112	76.12	0.0088	74.91	0.0070	71.92
0.0133	77.16	0.0101	76.26	0.0087	74.94
0.0156	77.79	0.0114	76.96	0.0098	76.59
0.0186	78.30	0.0130	77.42	0.0109	77.02
0.0221	78.77	0.0149	77.80	0.0122	77.30
0.0260	79.18	0.0180	78.26	0.0138	77.59
0.0300	79.53	0.0220	78.75	0.0156	77.91
0.0337	79.82	0.0265	79.22	0.0180	78.26
0.0370	80.06	0.0311	79.62	0.0210	78.64
0.0552	81.37	0.0603	81.78	0.0685	82.44
0.0630	82.01	0.0806	83.29	0.1141	85.11
0.0729	82.77	0.1080	84.82	0.1490	86.50
0.0994	84.39	0.1594	86.85	0.1965	87.94
0.1327	85.89	0.1942	87.88	0.2274	88.71
0.1714	87.23	0.2351	88.88	0.2494	89.19
0.2153	88.41	0.2829	89.84	0.3237	90.54
0.2647	89.49	0.3378	90.76	0.4081	91.74
0.3205	90.49	0.4006	91.65	0.5006	92.81
0.3840	91.43	0.4724	92.50	0.6009	93.76
0.4566	92.33	0.5540	93.33	0.7090	94.61
0.5401	93.20	0.6468	94.14	0.8245	95.40
0.6368	94.05	0.7522	94.92	0.9473	96.12
0.7492	94.90	0.8716	95.69	1.0773	96.79
0.8807	95.74	1.0070	96.44	1.2142	97.41
1.0351	96.58	1.1601	97.17	1.3581	97.99
1.2174	97.42	1.3333	97.89	1.5087	98.54
1.4336	98.27	1.5291	98.61	1.6659	99.05
1.6913	99.13	1.7502	99.31	1.8297	99.54
2.0000	100.00	2.0000	100.00	2.0000	100.00

https://doi.org/10.17221/139/2024-SWR

Table S5. Example 5 – Points of the resulting approximation curves with the uniform nodal vector of parametrization – B particle size distribution curve (d – particle size; p – percentage of fraction)

3rd degree curve		2nd degree curve		1st degree curve	
d (mm)	cumulative p (%)	d (mm)	cumulative p (%)	d (mm)	cumulative p (%)
0.0020	22.50	0.0020	22.50	0.0020	22.50
0.0034	22.73	0.0034	22.67	0.0029	22.50
0.0048	23.17	0.0049	22.99	0.0038	22.50
0.0062	23.68	0.0063	23.36	0.0047	22.50
0.0075	24.20	0.0077	23.74	0.0056	22.50
0.0087	24.72	0.0091	24.11	0.0064	22.50
0.0099	25.23	0.0104	24.48	0.0073	22.50
0.0111	25.72	0.0116	24.83	0.0081	22.50
0.0122	26.20	0.0128	25.16	0.0090	22.50
0.0217	30.21	0.0224	27.95	0.0171	26.13
0.0294	33.27	0.0297	30.30	0.0250	28.69
0.0362	35.78	0.0363	32.49	0.0326	30.51
0.0424	37.91	0.0424	34.49	0.0402	31.92
0.0482	39.79	0.0482	36.31	0.0476	33.07
0.0537	41.46	0.0537	37.99	0.0550	35.67
0.0589	42.98	0.0589	39.55	0.0622	38.67
0.0641	44.37	0.0640	41.00	0.0695	41.31
0.0691	45.66	0.0689	42.36	0.0766	43.67
0.1172	55.13	0.1118	52.75	0.1462	59.20
0.1416	58.56	0.1322	56.58	0.1800	64.20
0.1668	61.50	0.1544	59.83	0.2133	68.29
0.2204	66.41	0.2037	65.17	0.2880	74.00
0.2788	70.43	0.2596	69.50	0.3768	77.60
0.3427	73.87	0.3221	73.16	0.4693	80.55
0.4125	76.88	0.3914	76.34	0.5650	83.04
0.4885	79.57	0.4677	79.15	0.6635	85.20
0.5710	82.00	0.5511	81.68	0.7646	87.10
0.6603	84.22	0.6419	83.98	0.8681	88.80
0.7568	86.27	0.7403	86.09	0.9736	90.34
0.8607	88.18	0.8464	88.04	1.0812	91.75
0.9725	89.96	0.9605	89.86	1.1906	93.04
1.0923	91.63	1.0828	91.56	1.3017	94.24
1.2206	93.21	1.2134	93.16	1.4145	95.35
1.3576	94.70	1.3527	94.67	1.5288	96.39
1.5037	96.12	1.5007	96.10	1.6445	97.37
1.6593	97.47	1.6578	97.46	1.7617	98.30
1.8246	98.76	1.8242	98.76	1.8802	99.17
2.0000	100.00	2.0000	100.00	2.0000	100.00

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Table S6. Example 6 – Points of the resulting approximation curves with a non-uniform nodal vector of parametrization determined by the center of gravity method – B particle size distribution curve (d – particle size; p – percentage of fraction)

3rd degree curve		2nd degree curve		1st degree curve	
d (mm)	cumulative p (%)	d (mm)	cumulative p (%)	d (mm)	cumulative p (%)
0.0020	22.50	0.0020	22.50	0.0020	22.50
0.0041	22.81	0.0048	22.93	0.0109	23.06
0.0062	23.42	0.0082	23.76	0.0149	25.19
0.0083	24.10	0.0117	24.70	0.0190	26.84
0.0102	24.79	0.0151	25.67	0.0232	28.19
0.0120	25.47	0.0182	26.62	0.0274	29.33
0.0136	26.13	0.0210	27.54	0.0317	30.32
0.0152	26.77	0.0237	28.42	0.0361	31.19
0.0166	27.38	0.0263	29.25	0.0405	31.97
0.0282	32.41	0.0485	35.83	0.0709	41.81
0.0374	36.13	0.0654	40.56	0.0942	48.63
0.0458	39.11	0.0786	44.31	0.1152	53.47
0.0537	41.60	0.0896	47.40	0.1347	57.23
0.0613	43.75	0.1002	49.95	0.1530	60.29
0.0687	45.65	0.1104	52.11	0.1704	62.89
0.0759	47.34	0.1204	53.98	0.1871	65.13
0.0830	48.88	0.1303	55.63	0.2032	67.12
0.0900	50.29	0.1400	57.11	0.2187	68.89
0.1584	60.24	0.2331	66.90	0.3628	77.10
0.1927	63.69	0.2784	70.07	0.4281	79.32
0.2277	66.58	0.3235	72.67	0.4900	81.13
0.2999	71.28	0.4136	76.77	0.6065	83.99
0.3756	75.03	0.5042	79.97	0.7156	86.21
0.4551	78.16	0.5956	82.58	0.8192	88.02
0.5385	80.85	0.6882	84.80	0.9184	89.56
0.6259	83.21	0.7818	86.72	1.0139	90.89
0.7173	85.31	0.8767	88.42	1.1064	92.06
0.8128	87.20	0.9728	89.94	1.1963	93.11
0.9125	88.93	1.0701	91.32	1.2839	94.05
1.0163	90.52	1.1686	92.58	1.3695	94.92
1.1243	91.98	1.2684	93.74	1.4532	95.71
1.2365	93.35	1.3693	94.82	1.5353	96.45
1.3530	94.62	1.4715	95.82	1.6159	97.14
1.4738	95.82	1.5749	96.75	1.6951	97.78
1.5988	96.95	1.6794	97.63	1.7730	98.38
1.7282	98.02	1.7851	98.47	1.8497	98.95
1.8619	99.04	1.8920	99.25	1.9254	99.49
2.0000	100.00	2.0000	100.00	2.0000	100.00

https://doi.org/10.17221/139/2024-SWR

Table S7. Example 7 – Points of the resulting approximation curves with the uniform nodal vector of parametrization evaluated using particle-size distribution curve with embedded intermediate values by linear interpolation – B particle size distribution curve (*d* – particle size; *p* – percentage of fraction)

3rd degree curve		2nd degree curve		1st degree curve	
d (mm)	cumulative *p* (%)	*d* (mm)	cumulative *p* (%)	*d* (mm)	cumulative *p* (%)
0.0020	22.50	0.0020	22.50	0.0020	22.50
0.0034	22.51	0.0030	22.50	0.0025	22.50
0.0054	22.58	0.0046	22.50	0.0031	22.50
0.0070	22.68	0.0062	22.50	0.0040	22.50
0.0082	22.80	0.0074	22.50	0.0053	22.50
0.0090	22.94	0.0081	22.51	0.0063	22.50
0.0096	23.08	0.0087	22.57	0.0071	22.50
0.0101	23.23	0.0091	22.65	0.0078	22.50
0.0106	23.40	0.0095	22.75	0.0083	22.50
0.0154	25.47	0.0131	24.32	0.0117	23.59
0.0213	27.62	0.0185	26.68	0.0161	25.73
0.0273	29.30	0.0255	28.83	0.0236	28.33
0.0323	30.50	0.0319	30.36	0.0312	30.21
0.0363	31.38	0.0369	31.35	0.0368	31.32
0.0395	32.08	0.0405	32.01	0.0410	32.05
0.0420	32.66	0.0433	32.60	0.0443	32.58
0.0442	33.18	0.0457	33.17	0.0470	32.98
0.0460	33.65	0.0477	33.71	0.0493	33.30
0.0599	38.17	0.0654	39.85	0.0748	43.08
0.0676	40.83	0.0775	43.93	0.0957	49.00
0.0765	43.70	0.0927	48.25	0.1255	55.54
0.0979	49.57	0.1274	55.88	0.1725	63.18
0.1223	54.91	0.1596	61.31	0.2038	67.19
0.1475	59.34	0.1847	64.82	0.2263	69.71
0.1746	63.07	0.2066	67.30	0.2435	71.46
0.2057	66.36	0.2382	69.84	0.2901	74.09
0.2424	69.37	0.2796	72.43	0.3718	77.42
0.2864	72.22	0.3314	75.03	0.4642	80.40
0.3396	74.97	0.3949	77.61	0.5674	83.10
0.4046	77.66	0.4718	80.18	0.6816	85.56
0.4843	80.34	0.5647	82.72	0.8069	87.82
0.5826	83.02	0.6763	85.24	0.9432	89.92
0.7047	85.73	0.8102	87.74	1.0908	91.87
0.8572	88.47	0.9708	90.22	1.2497	93.69
1.0490	91.25	1.1632	92.69	1.4200	95.41
1.2919	94.10	1.3936	95.13	1.6018	97.02
1.6017	97.01	1.6695	97.57	1.7951	98.55
2.0000	100.00	2.0000	100.00	2.0000	100.00

https://doi.org/10.17221/139/2024-SWR

Table S8. Example 8 – Points of the resulting approximation curves with the non-uniform nodal vector of parametrization determined by center of gravity method. Particle-size distribution curve with intermediate values embedded by linear interpolation – B particle size distribution curve (d – particle size; p – percentage of fraction)

3rd degree curve		2nd degree curve		1st degree curve	
d (mm)	cumulative p (%)	d (mm)	cumulative p (%)	d (mm)	cumulative p (%)
0.0020	22.50	0.0020	22.50	0.0020	22.50
0.0097	23.00	0.0118	23.59	0.0025	22.50
0.0136	24.63	0.0193	26.95	0.0031	22.50
0.0191	26.89	0.0294	29.81	0.0040	22.50
0.0256	28.87	0.0364	31.26	0.0053	22.50
0.0314	30.31	0.0408	32.15	0.0063	22.50
0.0360	31.30	0.0441	32.87	0.0071	22.50
0.0394	32.02	0.0467	33.51	0.0078	22.50
0.0420	32.56	0.0490	34.10	0.0083	22.50
0.0545	35.96	0.0663	40.20	0.0117	23.59
0.0627	38.89	0.0859	46.41	0.0161	25.73
0.0707	41.71	0.1062	51.52	0.0236	28.33
0.0788	44.33	0.1249	55.40	0.0312	30.21
0.0870	46.70	0.1407	58.28	0.0368	31.32
0.0951	48.81	0.1535	60.36	0.0410	32.05
0.1032	50.71	0.1634	61.87	0.0443	32.58
0.1111	52.42	0.1712	62.98	0.0493	33.30
0.1190	53.96	0.1786	63.94	0.0748	43.08
0.1927	64.11	0.2528	70.41	0.0957	49.00
0.2274	67.28	0.2894	72.62	0.1255	55.54
0.2614	69.83	0.3260	74.49	0.1725	63.18
0.3289	73.80	0.3998	77.59	0.2038	67.19
0.3973	76.90	0.4754	80.14	0.2263	69.71
0.4678	79.46	0.5532	82.32	0.2435	71.46
0.5412	81.69	0.6336	84.25	0.2901	74.09
0.6181	83.66	0.7169	85.99	0.3718	77.42
0.6992	85.46	0.8034	87.58	0.4642	80.40
0.7848	87.12	0.8931	89.04	0.5674	83.10
0.8756	88.68	0.9863	90.41	0.6816	85.56
0.9718	90.14	1.0830	91.70	0.8069	87.82
1.0740	91.54	1.1835	92.91	0.9432	89.92
1.1827	92.87	1.2877	94.06	1.0908	91.87
1.2984	94.15	1.3960	95.15	1.2497	93.69
1.4215	95.39	1.5082	96.20	1.4200	95.41
1.5527	96.59	1.6246	97.20	1.6018	97.02
1.6924	97.75	1.7453	98.17	1.7951	98.55
2.0000	100.00	2.0000	100.00	2.0000	100.00