

# 格点 QCD 计算软件新框架计划

宫明

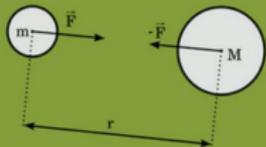
中国科学院高能物理研究所



2023 开放科学计算联盟学术年会  
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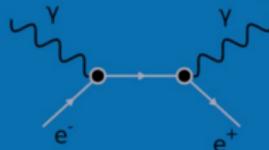
# 理论物理学对世界的理解

$$G_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + g_{\mu\nu}\Lambda = \frac{8\pi G}{c^4}T_{\mu\nu}$$



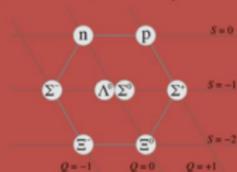
引力

$$\mathcal{L} = \bar{\psi} (i\gamma^\mu D_\mu - m) \psi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$



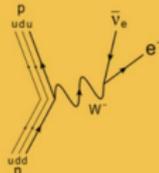
电磁力

$$\mathcal{L} = \bar{\psi}_i (i\gamma^\mu (D_\mu)_{ij} - m\delta_{ij}) \psi_j - \frac{1}{4}G_{\mu\nu}^a G_a^{\mu\nu}$$



强核力

$$\mathcal{L} = g(\bar{\nu}_{eL}, e^-)\gamma^\alpha \left\{ \begin{pmatrix} -\sqrt{1+\xi^2}Z_\mu & 0 \\ 0 & \frac{1-\gamma^5}{\sqrt{1+\xi^2}}Z_\mu \end{pmatrix} + \frac{1-\gamma^5}{4} \begin{pmatrix} -\sqrt{1+\xi^2}Z_\mu & -\sqrt{2}W_\mu^+ \\ -\sqrt{2}W_\mu^- & \sqrt{1+\xi^2}Z_\mu \end{pmatrix} \right\} \begin{pmatrix} \nu_{eL} \\ e^- \end{pmatrix}$$



弱核力

# 格点量子色动力学 (Lattice QCD)

## 唯一靠谱的研究强相互作用的方案

- 从第一原理出发 (没有手放进去的额外假设)
- 非微扰方法 (大多数情况下微扰方法对 QCD 无效)
- 误差可控 (系统误差与统计误差)

## 完全依赖计算机资源

- 基本方法是蒙特卡洛数值积分
  - 统计误差与计算资源的  $1/2$  次方成反比
  - 系统误差与计算资源的依赖更明显
- 主要计算核心是巨型稀疏矩阵乘法与线性方程组求解
  - 代码原理简洁, 实际应用规模巨大
  - 对浮点性能、通讯带宽、通讯延迟都有很高的要求。

# 计算资源需求

## 美国高能物理学在 E 级计算机上的需求预算

Computational Task	Current Usage	2025 Usage	Current Storage (Disk)	2025 Storage (Disk)	2025 Network Requirements (WAN)
Accelerator Modeling	~ 10M – 100M core-hrs/yr	~ 10G – 100G core-hrs/yr			
Computational Cosmology	~ 100M – 1G core-hrs/yr	~ 100G – 1000G core-hrs/yr	~10PB	>100PB	300Gb/s (burst)
Lattice QCD	~1G core-hrs/yr	~ 100G – 1000G core-hrs/yr	~1PB	>10PB	
Theory	~ 1M – 10M core-hrs/yr	~ 100M – 1G core-hrs/yr			
Cosmic Frontier Experiments	~ 10M – 100M core-hrs/yr	~ 1G – 10G core-hrs/yr	~1PB	10 – 100PB	
Energy Frontier Experiments	~ 100M core-hrs/yr	~ 10G – 100G core-hrs/yr	~1PB	>100PB	300Gb/s
Intensity Frontier Experiments	~ 10M core-hrs/yr	~ 100M – 1G core-hrs/yr	~1PB	10 – 100PB	300Gb/s

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<sup>1</sup> ASCR/HEP Exascale requirement review report, arxiv:1603.09303

# 格点 QCD 的软件配套

## USQCD 二十多年的软件积累

Chroma	CPS	FUEL	MILC	QLua
Inverters	MDWF	QOPQDP	QUDA	QPhiX
QDP++	QDP/C	QDP-JIT	Grid	
QLA	QMP	QMT	QIO	

## CLQCD 近年来面向 E 级超算的软件发展

- 向曙光平台移植了 QUDA 和 Chroma，并自研了 pyQuda 等软件
- 在申威平台上自研了 SWLQCD 的初步版本，通过 QSunway 接口集成到 Chroma
- 在天河三原型机上移植并优化了 Chroma 和 Grid
- 为天河三异构平台研发了 DDQ 的支持接口

# 脱钩的危险？弯道超车的机会？

## 当代的挑战

- 新硬件平台与老软件框架之间的矛盾
  - 裱糊不可取，离开屎山、不破不立！
- 物理学的思维方式与软件工程之间的矛盾
  - 需要用高度抽象的封装隔离物理学公式和代码实现！
- 巨大的工作量与捉襟见肘的人力资源之间的矛盾
  - 让合适的人做合适的事，让计算机做不适合人类的事！

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## 老笑话一则

数学家：你方程里的这几个量分别是什么？

物理学家：都是算符：D 是微分算符，U 是么正算符，S 是旋量算符。

数学家：这几个符号表示什么？

物理学家：都是函数：f(x) 是标量函数， $\delta(x)$  是德欧塔函数， $\Phi(x)$  是分布函数， $\phi(x)$  是波函数。

数学家： $A_\mu(x)$  也是函数？

物理学家：不， $A_\mu(x)$  是个场。

把各种物理量都分别实现为对应的程序对象？让程序具有物理意义？

不！这不是软件工程的思维方式。

PHAME (Principles of Hierarchy, Abstraction, Modularisation, and Encapsulation)



# 脱钩的危险？弯道超车的机会？

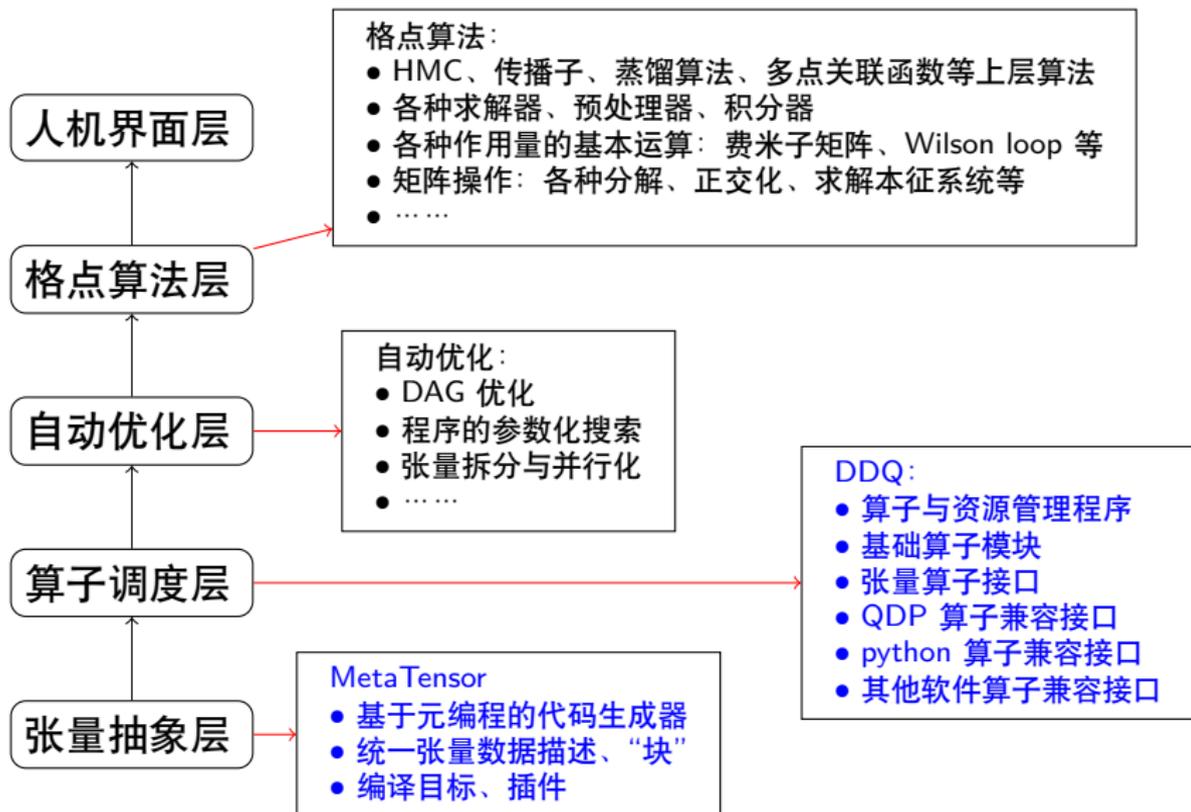
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  - 让合适的人做合适的事，让计算机做不适合人类的事！

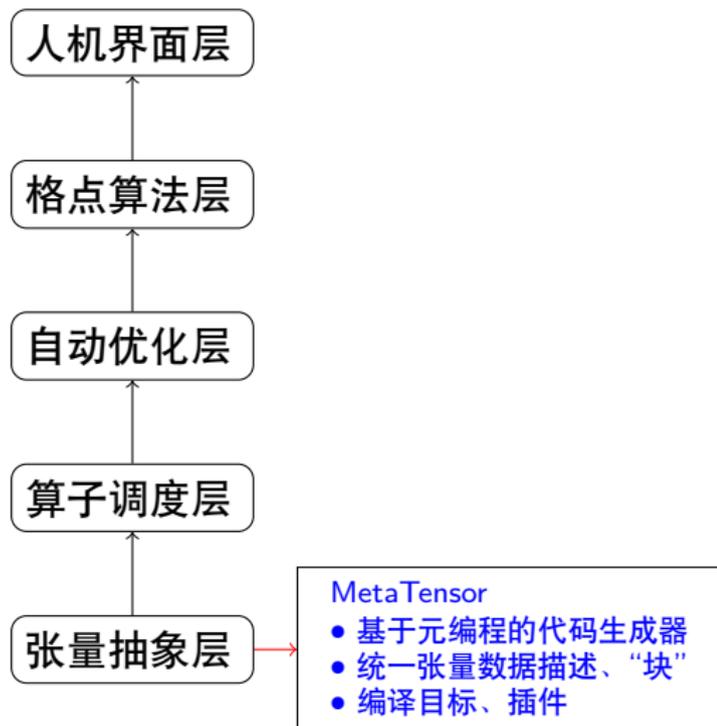
## 新软件框架的设计原则

- 要对各种硬件平台提出极简的抽象接口，并用其对代码分层
- 要对各种物理计算需求提出极简的抽象接口，并用其对代码分层
- 要保留一些适合自动优化的透明接口，对人工智能虚位以待

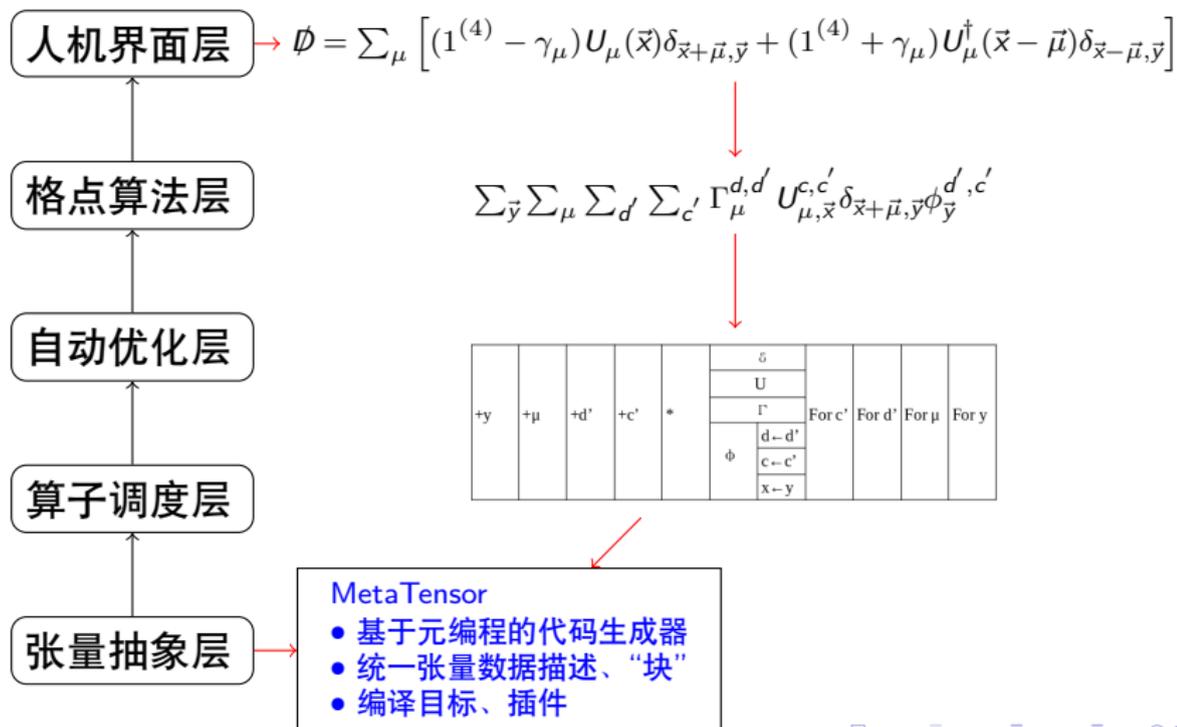
# 格点 QCD 新软件框架设计



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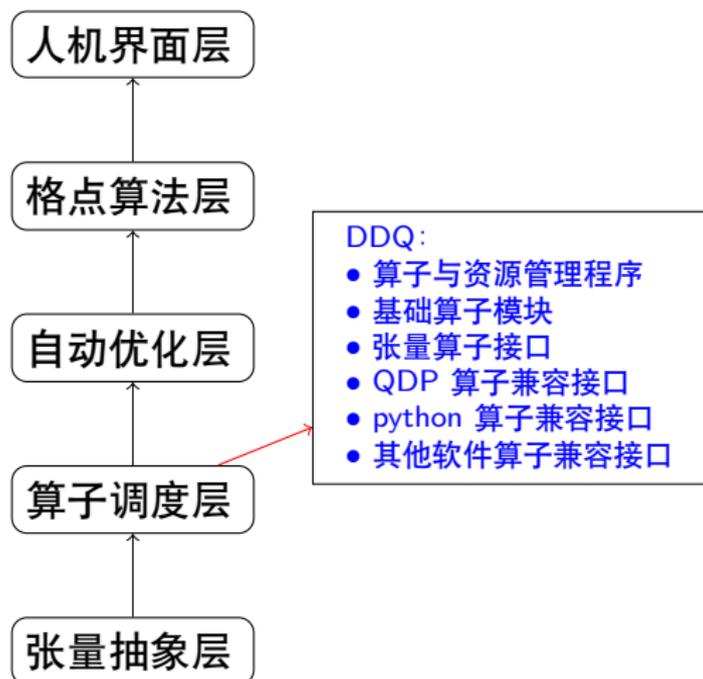




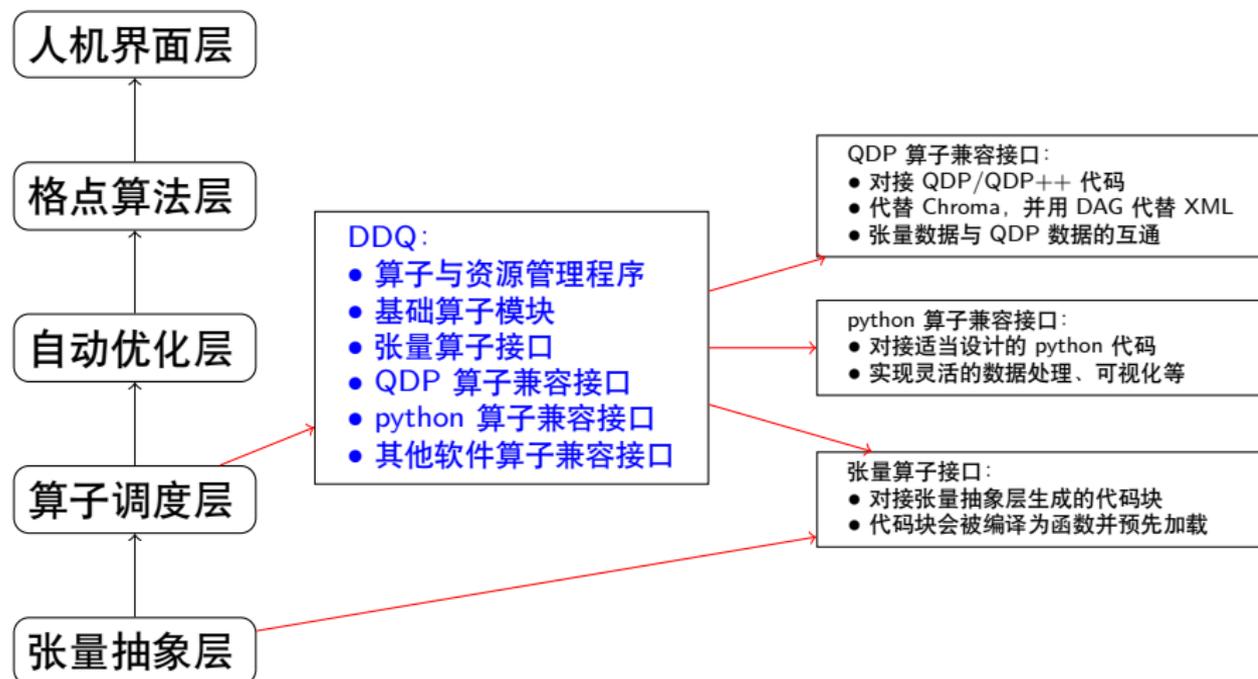
# 格点 QCD 新软件框架设计

```
int main() {  
    int x = 1, y = 2, z = 3;  
    int a = 4, b = 5, c = 6;  
    int d = 7, e = 8, f = 9;  
    int g = 10, h = 11, i = 12;  
    int j = 13, k = 14, l = 15;  
    int m = 16, n = 17, o = 18;  
    int p = 19, q = 20, r = 21;  
    int s = 22, t = 23, u = 24;  
    int v = 25, w = 26, x = 27;  
    int y = 28, z = 29, a = 30;  
    int b = 31, c = 32, d = 33;  
    int e = 34, f = 35, g = 36;  
    int h = 37, i = 38, j = 39;  
    int k = 40, l = 41, m = 42;  
    int n = 43, o = 44, p = 45;  
    int q = 46, r = 47, s = 48;  
    int t = 49, u = 50, v = 51;  
    int w = 52, x = 53, y = 54;  
    int z = 55, a = 56, b = 57;  
    int c = 58, d = 59, e = 60;  
    int f = 61, g = 62, h = 63;  
    int i = 64, j = 65, k = 66;  
    int l = 67, m = 68, n = 69;  
    int o = 70, p = 71, q = 72;  
    int r = 73, s = 74, t = 75;  
    int u = 76, v = 77, w = 78;  
    int x = 79, y = 80, z = 81;  
    int a = 82, b = 83, c = 84;  
    int d = 85, e = 86, f = 87;  
    int g = 88, h = 89, i = 90;  
    int j = 91, k = 92, l = 93;  
    int m = 94, n = 95, o = 96;  
    int p = 97, q = 98, r = 99;  
    int s = 100, t = 101, u = 102;  
    int v = 103, w = 104, x = 105;  
    int y = 106, z = 107, a = 108;  
    int b = 109, c = 110, d = 111;  
    int e = 112, f = 113, g = 114;  
    int h = 115, i = 116, j = 117;  
    int k = 118, l = 119, m = 120;  
    int n = 121, o = 122, p = 123;  
    int q = 124, r = 125, s = 126;  
    int t = 127, u = 128, v = 129;  
    int w = 130, x = 131, y = 132;  
    int z = 133, a = 134, b = 135;  
    int c = 136, d = 137, e = 138;  
    int f = 139, g = 140, h = 141;  
    int i = 142, j = 143, k = 144;  
    int l = 145, m = 146, n = 147;  
    int o = 148, p = 149, q = 150;  
    int r = 151, s = 152, t = 153;  
    int u = 154, v = 155, w = 156;  
    int x = 157, y = 158, z = 159;  
    int a = 160, b = 161, c = 162;  
    int d = 163, e = 164, f = 165;  
    int g = 166, h = 167, i = 168;  
    int j = 169, k = 170, l = 171;  
    int m = 172, n = 173, o = 174;  
    int p = 175, q = 176, r = 177;  
    int s = 178, t = 179, u = 180;  
    int v = 181, w = 182, x = 183;  
    int y = 184, z = 185, a = 186;  
    int b = 187, c = 188, d = 189;  
    int e = 190, f = 191, g = 192;  
    int h = 193, i = 194, j = 195;  
    int k = 196, l = 197, m = 198;  
    int n = 199, o = 200, p = 201;  
    int q = 202, r = 203, s = 204;  
    int t = 205, u = 206, v = 207;  
    int w = 208, x = 209, y = 210;  
    int z = 211, a = 212, b = 213;  
    int c = 214, d = 215, e = 216;  
    int f = 217, g = 218, h = 219;  
    int i = 220, j = 221, k = 222;  
    int l = 223, m = 224, n = 225;  
    int o = 226, p = 227, q = 228;  
    int r = 229, s = 230, t = 231;  
    int u = 232, v = 233, w = 234;  
    int x = 235, y = 236, z = 237;  
    int a = 238, b = 239, c = 240;  
    int d = 241, e = 242, f = 243;  
    int g = 244, h = 245, i = 246;  
    int j = 247, k = 248, l = 249;  
    int m = 250, n = 251, o = 252;  
    int p = 253, q = 254, r = 255;  
    int s = 256, t = 257, u = 258;  
    int v = 259, w = 260, x = 261;  
    int y = 262, z = 263, a = 264;  
    int b = 265, c = 266, d = 267;  
    int e = 268, f = 269, g = 270;  
    int h = 271, i = 272, j = 273;  
    int k = 274, l = 275, m = 276;  
    int n = 277, o = 278, p = 279;  
    int q = 280, r = 281, s = 282;  
    int t = 283, u = 284, v = 285;  
    int w = 286, x = 287, y = 288;  
    int z = 289, a = 290, b = 291;  
    int c = 292, d = 293, e = 294;  
    int f = 295, g = 296, h = 297;  
    int i = 298, j = 299, k = 300;  
    int l = 301, m = 302, n = 303;  
    int o = 304, p = 305, q = 306;  
    int r = 307, s = 308, t = 309;  
    int u = 310, v = 311, w = 312;  
    int x = 313, y = 314, z = 315;  
    int a = 316, b = 317, c = 318;  
    int d = 319, e = 320, f = 321;  
    int g = 322, h = 323, i = 324;  
    int j = 325, k = 326, l = 327;  
    int m = 328, n = 329, o = 330;  
    int p = 331, q = 332, r = 333;  
    int s = 334, t = 335, u = 336;  
    int v = 337, w = 338, x = 339;  
    int y = 340, z = 341, a = 342;  
    int b = 343, c = 344, d = 345;  
    int e = 346, f = 347, g = 348;  
    int h = 349, i = 350, j = 351;  
    int k = 352, l = 353, m = 354;  
    int n = 355, o = 356, p = 357;  
    int q = 358, r = 359, s = 360;  
    int t = 361, u = 362, v = 363;  
    int w = 364, x = 365, y = 366;  
    int z = 367, a = 368, b = 369;  
    int c = 370, d = 371, e = 372;  
    int f = 373, g = 374, h = 375;  
    int i = 376, j = 377, k = 378;  
    int l = 379, m = 380, n = 381;  
    int o = 382, p = 383, q = 384;  
    int r = 385, s = 386, t = 387;  
    int u = 388, v = 389, w = 390;  
    int x = 391, y = 392, z = 393;  
    int a = 394, b = 395, c = 396;  
    int d = 397, e = 398, f = 399;  
    int g = 400, h = 401, i = 402;  
    int j = 403, k = 404, l = 405;  
    int m = 406, n = 407, o = 408;  
    int p = 409, q = 410, r = 411;  
    int s = 412, t = 413, u = 414;  
    int v = 415, w = 416, x = 417;  
    int y = 418, z = 419, a = 420;  
    int b = 421, c = 422, d = 423;  
    int e = 424, f = 425, g = 426;  
    int h = 427, i = 428, j = 429;  
    int k = 430, l = 431, m = 432;  
    int n = 433, o = 434, p = 435;  
    int q = 436, r = 437, s = 438;  
    int t = 439, u = 440, v = 441;  
    int w = 442, x = 443, y = 444;  
    int z = 445, a = 446, b = 447;  
    int c = 448, d = 449, e = 450;  
    int f = 451, g = 452, h = 453;  
    int i = 454, j = 455, k = 456;  
    int l = 457, m = 458, n = 459;  
    int o = 460, p = 461, q = 462;  
    int r = 463, s = 464, t = 465;  
    int u = 466, v = 467, w = 468;  
    int x = 469, y = 470, z = 471;  
    int a = 472, b = 473, c = 474;  
    int d = 475, e = 476, f = 477;  
    int g = 478, h = 479, i = 480;  
    int j = 481, k = 482, l = 483;  
    int m = 484, n = 485, o = 486;  
    int p = 487, q = 488, r = 489;  
    int s = 490, t = 491, u = 492;  
    int v = 493, w = 494, x = 495;  
    int y = 496, z = 497, a = 498;  
    int b = 499, c = 500, d = 501;  
    int e = 502, f = 503, g = 504;  
    int h = 505, i = 506, j = 507;  
    int k = 508, l = 509, m = 510;  
    int n = 511, o = 512, p = 513;  
    int q = 514, r = 515, s = 516;  
    int t = 517, u = 518, v = 519;  
    int w = 520, x = 521, y = 522;  
    int z = 523, a = 524, b = 525;  
    int c = 526, d = 527, e = 528;  
    int f = 529, g = 530, h = 531;  
    int i = 532, j = 533, k = 534;  
    int l = 535, m = 536, n = 537;  
    int o = 538, p = 539, q = 540;  
    int r = 541, s = 542, t = 543;  
    int u = 544, v = 545, w = 546;  
    int x = 547, y = 548, z = 549;  
    int a = 550, b = 551, c = 552;  
    int d = 553, e = 554, f = 555;  
    int g = 556, h = 557, i = 558;  
    int j = 559, k = 560, l = 561;  
    int m = 562, n = 563, o = 564;  
    int p = 565, q = 566, r = 567;  
    int s = 568, t = 569, u = 570;  
    int v = 571, w = 572, x = 573;  
    int y = 574, z = 575, a = 576;  
    int b = 577, c = 578, d = 579;  
    int e = 580, f = 581, g = 582;  
    int h = 583, i = 584, j = 585;  
    int k = 586, l = 587, m = 588;  
    int n = 589, o = 590, p = 591;  
    int q = 592, r = 593, s = 594;  
    int t = 595, u = 596, v = 597;  
    int w = 598, x = 599, y = 600;  
    int z = 601, a = 602, b = 603;  
    int c = 604, d = 605, e = 606;  
    int f = 607, g = 608, h = 609;  
    int i = 610, j = 611, k = 612;  
    int l = 613, m = 614, n = 615;  
    int o = 616, p = 617, q = 618;  
    int r = 619, s = 620, t = 621;  
    int u = 622, v = 623, w = 624;  
    int x = 625, y = 626, z = 627;  
    int a = 628, b = 629, c = 630;  
    int d = 631, e = 632, f = 633;  
    int g = 634, h = 635, i = 636;  
    int j = 637, k = 638, l = 639;  
    int m = 640, n = 641, o = 642;  
    int p = 643, q = 644, r = 645;  
    int s = 646, t = 647, u = 648;  
    int v = 649, w = 650, x = 651;  
    int y = 652, z = 653, a = 654;  
    int b = 655, c = 656, d = 657;  
    int e = 658, f = 659, g = 660;  
    int h = 661, i = 662, j = 663;  
    int k = 664, l = 665, m = 666;  
    int n = 667, o = 668, p = 669;  
    int q = 670, r = 671, s = 672;  
    int t = 673, u = 674, v = 675;  
    int w = 676, x = 677, y = 678;  
    int z = 679, a = 680, b = 681;  
    int c = 682, d = 683, e = 684;  
    int f = 685, g = 686, h = 687;  
    int i = 688, j = 689, k = 690;  
    int l = 691, m = 692, n = 693;  
    int o = 694, p = 695, q = 696;  
    int r = 697, s = 698, t = 699;  
    int u = 700, v = 701, w = 702;  
    int x = 703, y = 704, z = 705;  
    int a = 706, b = 707, c = 708;  
    int d = 709, e = 710, f = 711;  
    int g = 712, h = 713, i = 714;  
    int j = 715, k = 716, l = 717;  
    int m = 718, n = 719, o = 720;  
    int p = 721, q = 722, r = 723;  
    int s = 724, t = 725, u = 726;  
    int v = 727, w = 728, x = 729;  
    int y = 730, z = 731, a = 732;  
    int b = 733, c = 734, d = 735;  
    int e = 736, f = 737, g = 738;  
    int h = 739, i = 740, j = 741;  
    int k = 742, l = 743, m = 744;  
    int n = 745, o = 746, p = 747;  
    int q = 748, r = 749, s = 750;  
    int t = 751, u = 752, v = 753;  
    int w = 754, x = 755, y = 756;  
    int z = 757, a = 758, b = 759;  
    int c = 760, d = 761, e = 762;  
    int f = 763, g = 764, h = 765;  
    int i = 766, j = 767, k = 768;  
    int l = 769, m = 770, n = 771;  
    int o = 772, p = 773, q = 774;  
    int r = 775, s = 776, t = 777;  
    int u = 778, v = 779, w = 780;  
    int x = 781, y = 782, z = 783;  
    int a = 784, b = 785, c = 786;  
    int d = 787, e = 788, f = 789;  
    int g = 790, h = 791, i = 792;  
    int j = 793, k = 794, l = 795;  
    int m = 796, n = 797, o = 798;  
    int p = 799, q = 800, r = 801;  
    int s = 802, t = 803, u = 804;  
    int v = 805, w = 806, x = 807;  
    int y = 808, z = 809, a = 810;  
    int b = 811, c = 812, d = 813;  
    int e = 814, f = 815, g = 816;  
    int h = 817, i = 818, j = 819;  
    int k = 820, l = 821, m = 822;  
    int n = 823, o = 824, p = 825;  
    int q = 826, r = 827, s = 828;  
    int t = 829, u = 830, v = 831;  
    int w = 832, x = 833, y = 834;  
    int z = 835, a = 836, b = 837;  
    int c = 838, d = 839, e = 840;  
    int f = 841, g = 842, h = 843;  
    int i = 844, j = 845, k = 846;  
    int l = 847, m = 848, n = 849;  
    int o = 850, p = 851, q = 852;  
    int r = 853, s = 854, t = 855;  
    int u = 856, v = 857, w = 858;  
    int x = 859, y = 860, z = 861;  
    int a = 862, b = 863, c = 864;  
    int d = 865, e = 866, f = 867;  
    int g = 868, h = 869, i = 870;  
    int j = 871, k = 872, l = 873;  
    int m = 874, n = 875, o = 876;  
    int p = 877, q = 878, r = 879;  
    int s = 880, t = 881, u = 882;  
    int v = 883, w = 884, x = 885;  
    int y = 886, z = 887, a = 888;  
    int b = 889, c = 890, d = 891;  
    int e = 892, f = 893, g = 894;  
    int h = 895, i = 896, j = 897;  
    int k = 898, l = 899, m = 900;  
    int n = 901, o = 902, p = 903;  
    int q = 904, r = 905, s = 906;  
    int t = 907, u = 908, v = 909;  
    int w = 910, x = 911, y = 912;  
    int z = 913, a = 914, b = 915;  
    int c = 916, d = 917, e = 918;  
    int f = 919, g = 920, h = 921;  
    int i = 922, j = 923, k = 924;  
    int l = 925, m = 926, n = 927;  
    int o = 928, p = 929, q = 930;  
    int r = 931, s = 932, t = 933;  
    int u = 934, v = 935, w = 936;  
    int x = 937, y = 938, z = 939;  
    int a = 940, b = 941, c = 942;  
    int d = 943, e = 944, f = 945;  
    int g = 946, h = 947, i = 948;  
    int j = 949, k = 950, l = 951;  
    int m = 952, n = 953, o = 954;  
    int p = 955, q = 956, r = 957;  
    int s = 958, t = 959, u = 960;  
    int v = 961, w = 962, x = 963;  
    int y = 964, z = 965, a = 966;  
    int b = 967, c = 968, d = 969;  
    int e = 970, f = 971, g = 972;  
    int h = 973, i = 974, j = 975;  
    int k = 976, l = 977, m = 978;  
    int n = 979, o = 980, p = 981;  
    int q = 982, r = 983, s = 984;  
    int t = 985, u = 986, v = 987;  
    int w = 988, x = 989, y = 990;  
    int z = 991, a = 992, b = 993;  
    int c = 994, d = 995, e = 996;  
    int f = 997, g = 998, h = 999;  
    int i = 1000, j = 1001, k = 1002;  
    int l = 1003, m = 1004, n = 1005;  
    int o = 1006, p = 1007, q = 1008;  
    int r = 1009, s = 1010, t = 1011;  
    int u = 1012, v = 1013, w = 1014;  
    int x = 1015, y = 1016, z = 1017;  
    int a = 1018, b = 1019, c = 1020;  
    int d = 1021, e = 1022, f = 1023;  
    int g = 1024, h = 1025, i = 1026;  
    int j = 1027, k = 1028, l = 1029;  
    int m = 1030, n = 1031, o = 1032;  
    int p = 1033, q = 1034, r = 1035;  
    int s = 1036, t = 1037, u = 1038;  
    int v = 1039, w = 1040, x = 1041;  
    int y = 1042, z = 1043, a = 1044;  
    int b = 1045, c = 1046, d = 1047;  
    int e = 1048, f = 1049, g = 1050;  
    int h = 1051, i = 1052, j = 1053;  
    int k = 1054, l = 1055, m = 1056;  
    int n = 1057, o = 1058, p = 1059;  
    int q = 1060, r = 1061, s = 1062;  
    int t = 1063, u = 1064, v = 1065;  
    int w = 1066, x = 1067, y = 1068;  
    int z = 1069, a = 1070, b = 1071;  
    int c = 1072, d = 1073, e = 1074;  
    int f = 1075, g = 1076, h = 1077;  
    int i = 1078, j = 1079, k = 1080;  
    int l = 1081, m = 1082, n = 1083;  
    int o = 1084, p = 1085, q = 1086;  
    int r = 1087, s = 1088, t = 1089;  
    int u = 1090, v = 1091, w = 1092;  
    int x = 1093, y = 1094, z = 1095;  
    int a = 1096, b = 1097, c = 1098;  
    int d = 1099, e = 1100, f = 1101;  
    int g = 1102, h = 1103, i = 1104;  
    int j = 1105, k = 1106, l = 1107;  
    int m = 1108, n = 1109, o = 1110;  
    int p = 1111, q = 1112, r = 1113;  
    int s = 1114, t = 1115, u = 1116;  
    int v = 1117, w = 1118, x = 1119;  
    int y = 1120, z = 1121, a = 1122;  
    int b = 1123, c = 1124, d = 1125;  
    int e = 1126, f = 1127, g = 1128;  
    int h = 1129, i = 1130, j = 1131;  
    int k = 1132, l = 1133, m = 1134;  
    int n = 1135, o = 1136, p = 1137;  
    int q = 1138, r = 1139, s = 1140;  
    int t = 1141, u = 1142, v = 1143;  
    int w = 1144, x = 1145, y = 1146;  
    int z = 1147, a = 1148, b = 1149;  
    int c = 1150, d = 1151, e = 1152;  
    int f = 1153, g = 1154, h = 1155;  
    int i = 1156, j = 1157, k = 1158;  
    int l = 1159, m = 1160, n = 1161;  
    int o = 1162, p = 1163, q = 1164;  
    int r = 1165, s = 1166, t = 1167;  
    int u = 1168, v = 1169, w = 1170;  
    int x = 1171, y = 1172, z = 1173;  
    int a = 1174, b = 1175, c = 1176;  
    int d = 1177, e = 1178, f = 1179;  
    int g = 1180, h = 1181, i = 1182;  
    int j = 1183, k = 1184, l = 1185;  
    int m = 1186, n = 1187, o = 1188;  
    int p = 1189, q = 1190, r = 1191;  
    int s = 1192, t = 1193, u = 1194;  
    int v = 1195, w = 1196, x = 1197;  
    int y = 1198, z = 1199, a = 1200;  
    int b = 1201, c = 1202, d = 1203;  
    int e = 1204, f = 1205, g = 1206;  
    int h = 1207, i = 1208, j = 1209;  
    int k = 1210, l = 1211, m = 1212;  
    int n = 1213, o = 1214, p = 1215;  
    int q = 1216, r = 1217, s = 1218;  
    int t = 1219, u = 1220, v = 1221;  
    int w = 1222, x = 1223, y = 1224;  
    int z = 1225, a = 1226, b = 1227;  
    int c = 1228, d = 1229, e = 1230;  
    int f = 1231, g = 1232, h = 1233;  
    int i = 1234, j = 1235, k = 1236;  
    int l = 1237, m = 1238, n = 1239;  
    int o = 1240, p = 1241, q = 1242;  
    int r = 1243, s = 1244, t = 1245;  
    int u = 1246, v = 1247, w = 1248;  
    int x = 1249, y = 1250, z = 1251;  
    int a = 1252, b = 1253, c = 1254;  
    int d = 1255, e = 1256, f = 1257;  
    int g = 1258, h = 1259, i = 1260;  
    int j = 1261, k = 1262, l = 1263;  
    int m = 1264, n = 1265, o = 1266;  
    int p = 1267, q = 1268, r = 1269;  
    int s = 1270, t = 1271, u = 1272;  
    int v = 1273, w = 1274, x = 1275;  
    int y = 1276, z = 1277, a = 1278;  
    int b = 1279, c = 1280, d = 1281;  
    int e = 1282, f = 1283, g = 1284;  
    int h = 1285, i = 1286, j = 1287;  
    int k = 1288, l = 1289, m = 1290;  
    int n = 1291, o = 1292, p = 1293;  
    int q = 1294, r = 1295, s = 1296;  
    int t = 1297, u = 1298, v = 1299;  
    int w = 1300, x = 1301, y = 1302;  
    int z = 1303, a = 1304, b = 1305;  
    int c = 1306, d = 1307, e = 1308;  
    int f = 1309, g = 1310, h = 1311;  
    int i = 1312, j = 1313, k = 1314;  
    int l = 1315, m = 1316, n = 1317;  
    int o = 1318, p = 1319, q = 1320;  
    int r = 1321, s = 1322, t = 1323;  
    int u = 1324, v = 1325, w = 1326;  
    int x = 1327, y = 1328, z = 1329;  
    int a = 1330, b = 1331, c = 1332;  
    int d = 1333, e = 1334, f = 1335;  
    int g = 1336, h = 1337, i = 1338;  
    int j = 1339, k = 1340, l = 1341;  
    int m = 1342, n = 1343, o = 1344;  
    int p = 1345, q = 1346, r = 1347;  
    int s = 1348, t = 1349, u = 1350;  
    int v = 1351, w = 1352, x = 1353;  
    int y = 1354, z = 1355, a = 1356;  
    int b = 1357, c = 1358, d = 1359;  
    int e = 1360, f = 1361, g = 1362;  
    int h = 1363, i = 1364, j = 1365;  
    int k = 1366, l = 1367, m = 1368;  
    int n = 1369, o = 1370, p = 1371;  
    int q = 1372, r = 1373, s = 1374;  
    int t = 1375, u = 1376, v = 1377;  
    int w = 1378, x = 1379, y = 1380;  
    int z = 1381, a = 1382, b = 1383;  
    int c = 1384, d = 1385, e = 1386;  
    int f = 1387, g = 1388, h = 1389;  
    int i = 1390, j = 1391, k = 1392;  
    int l = 1393, m = 1394, n = 1395;  
    int o = 1396, p = 1397, q = 1398;  
    int r = 1399, s = 1400, t = 1401;  
    int u = 1402, v = 1403, w = 1404;  
    int x = 1405, y = 1406, z = 1407;  
    int a = 1408, b = 1409, c = 1410;  
    int d = 1411, e = 1412, f = 1413;  
    int g = 1414, h = 1415, i = 1416;  
    int j = 1417, k = 1418, l = 1419;  
    int m = 1420, n = 1421, o = 1422;  
    int p = 1423, q = 1424, r = 1425;  
    int s = 1426, t = 1427, u = 1428;  
    int v = 1429, w = 1430, x = 1431;  
    int y = 1432, z = 1433, a = 1434;  
    int b = 1435, c = 1436, d = 1437;<
```

# 格点 QCD 新软件框架设计



# 格点 QCD 新软件框架设计



# 格点 QCD 新软件框架设计



```
task_ret      f_print(void **inputs, void **outputs);
task_ret      f_add(void **inputs, void **outputs);

int main()
{
    obj      f_a, f_p, a, b;
    ddq_op   ab, ba, pa, pb;

    unsigned long  a0, b0;
    a0 = b0 = 1;

    f_a = obj_import(f_add, NULL, obj_prop_ready);
    f_p = obj_import(f_print, NULL, obj_prop_ready);

    a = obj_import(&a0, NULL, obj_prop_consumable | obj_prop_ready);
    b = obj_import(&b0, NULL, obj_prop_consumable);

    ab = ddq_spawn(processor_pthread, 1, 1);
    ab->f = f_a;
    ab->inputs[0] = a;
    ab->outputs[0] = b;

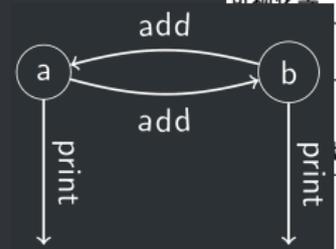
    ba = ddq_spawn(processor_pthread, 1, 1);
    ba->f = f_a;
    ba->inputs[0] = b;
    ba->outputs[0] = a;

    pa = ddq_spawn(processor_pthread, 1, 0);
    pa->f = f_p;
    pa->inputs[0] = a;

    pb = ddq_spawn(processor_pthread, 1, 0);
    pb->f = f_p;
    pb->inputs[0] = b;

    ddq_loop();

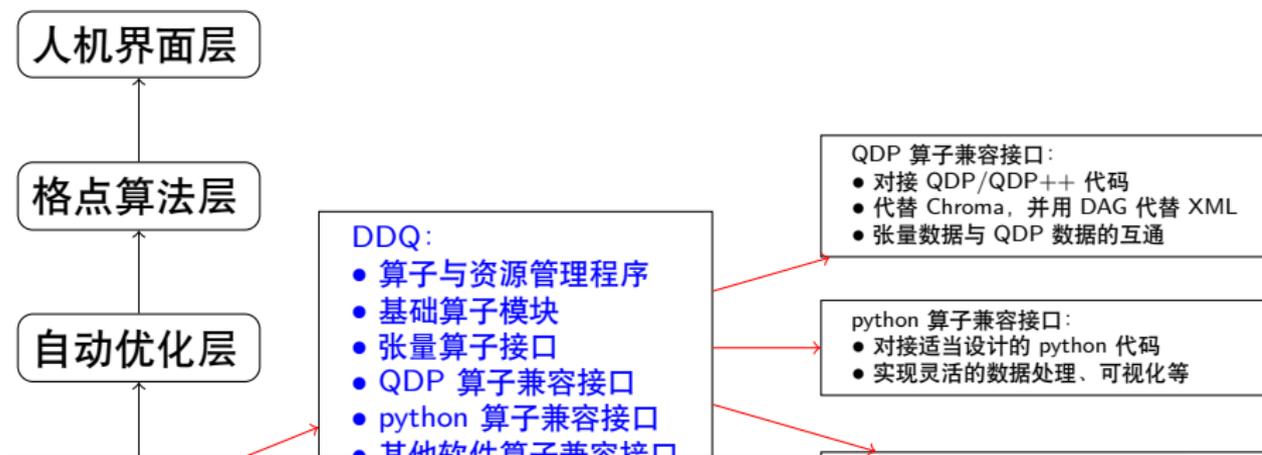
    return 0;
}
```



代码  
TAG 代替 XML  
的互通

代码  
可视化等

# 格点 QCD 新软件框架设计



- DDQ 是一个运行时的算子调度器，能根据依赖关系动态安排算子的运行
- 它是跨平台的，通过插件支持各种硬件设备
  - 目前已初步支持了 CPU 单核、多核、GPU、天河三 DSP 等处理器
- 它可以自动实现异构并行化、双缓冲优化等等

# 目前状态

## 分层进展情况

- 张量抽象层的 MetaTensor 的设计环节基本完成，代码工作进展顺利
- 算子调度层的 DDQ 已初步成型，目前测试正常，正在继续完善
- 自动优化层的预研工作得到了乐观的结果，目前留出接口即可
- 格点算法层早已预研完成，等待底层工作完成后再开始研发
- 人机界面层初步设计了基于图形界面的新编程语言

## 预期进展

- 2 年内，实现最底两层的基本功能
- 4 年内，实现格点 QCD 的实用计算
- 未来保持持续更新，并积极研发新算法进行自动优化

## 资金支持

- 基金委重大项目《基于国产超算的格点量子色动力学关键科学问题研究》(2023-2027 年) 的子课题《基于国产超算的格点软件与数据》的主要任务

# 谢谢!