Performance vs. flexibility: towards a BG/Q code for general Lattice-Gauge-Theory applications

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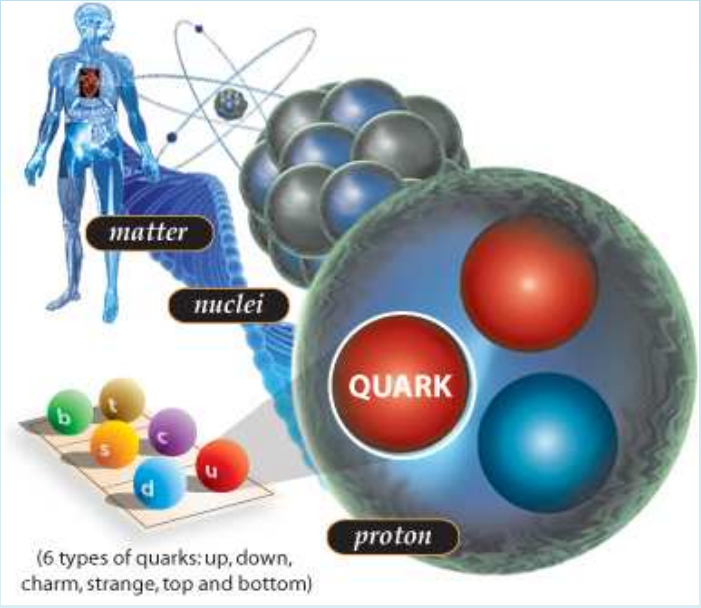
Quarks: in the Heart of Matter



Interior of the atom: nucleus, made up of nucleons, made up of quarks

In nature there are 6 types (flavors) of quarks [as well as 6 types of leptons (e.g. electron, neutrino)]

Hadrons (e.g. protons, neutrons, mesons) are made up of quarks

Ordinary matter is made up of only the two lightest flavors of quarks (and leptons)

Protons and Neutrons:

- 99% of the mass of the bound state comes from the interaction!

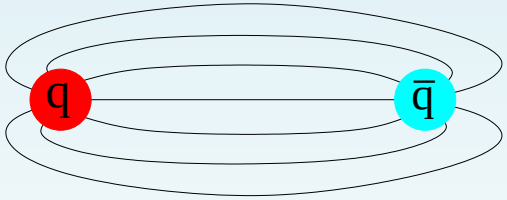
QCD vs. QED

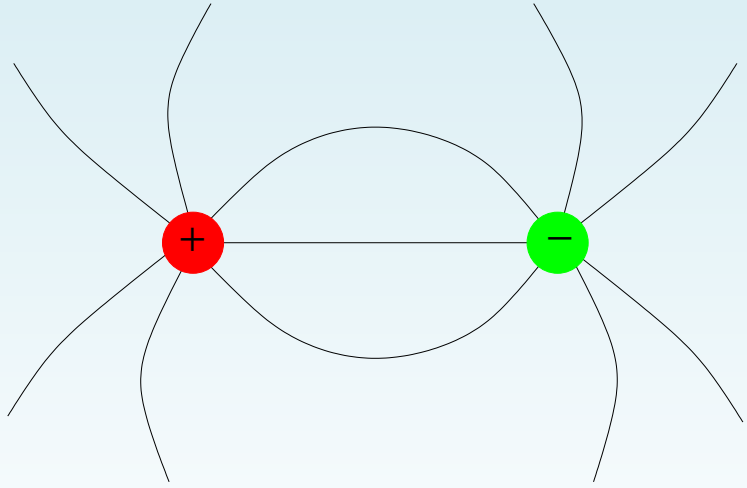
QCD (strong force) vs. QED (EM force)

quarks, gluons | electrons, photons

$SU(3)$ (3 "colors") | $U(1)$

m_q, $\alpha_s(p)$ | m_e, $\alpha \approx 1/137$

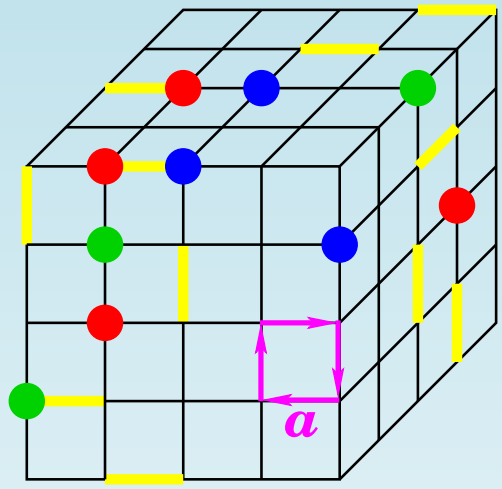




QCD on a Lattice

Three ingredients

1. Quantization by path integrals $\Rightarrow$ sum over configurations with "weights" $e^{i\,S/\hbar}$
2. Euclidean formulation (analytic continuation to imaginary time) $\Rightarrow$ weight becomes $e^{-S/\hbar}$
3. Discrete space-time $\Rightarrow$ UV cut at momenta $p \lesssim 1/a$ $\Rightarrow$ regularization



Also: finite-size lattices $\Rightarrow$ IR cut for small momenta $p \approx 1/L$

The Wilson action

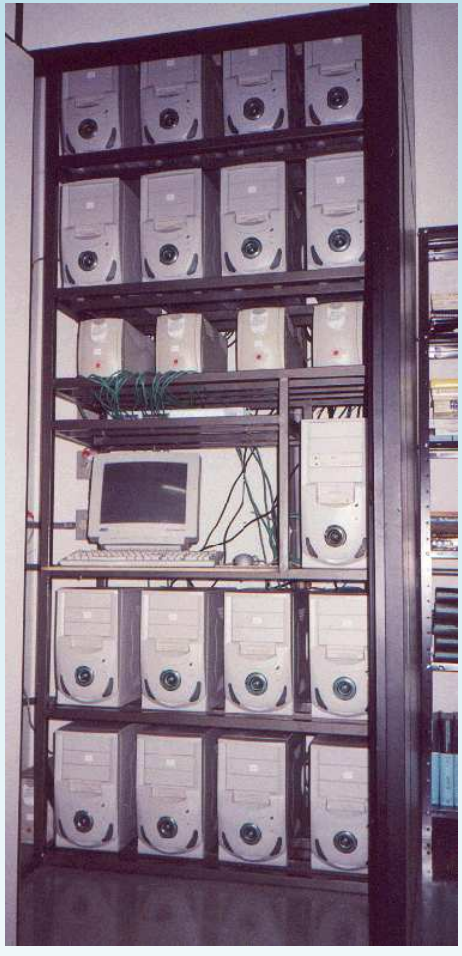
- is written for the gauge links $U_{x,\mu} \equiv e^{ig_0 a A^b_\mu(x) T_b}$
- reduces to the usual action for $a \to 0$
- is gauge-invariant

Lattice QCD at the IFSC–USP

The only LQCD group (A.C. & T. Mendes) in South America.

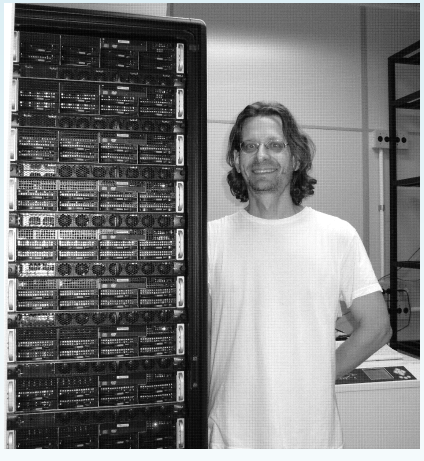
1. Study of qualitative aspects of QCD: infrared behavior of propagators and vertices, related to color confinement and to color deconfinement (at high temperature).
2. Development of methods: determination of the strong coupling constant $\alpha_s(p)$ to be applied to the full QCD case, lattice implementation of different analytic approaches (linear covariant gauge, background-field gauge).
3. Development of algorithms: gauge fixing, global minimization, matrix inversion, evaluation of eigenvalues.

Old Computer Facilities



2001

2007



2010

2012

From a Pentium III PC-cluster, to the IBM Ma-mute, an Intel Xeon cluster and the Blue Gene P.

Results from the BG/P

- New lower bound for the smallest nonzero eigenvalue of the Landau-gauge Faddeev-Popov matrix in Yang-Mills theories.
- First candidate for a lattice configuration belonging to the common boundary $\partial\Omega \cap \partial\Lambda$.
- First estimate of the distance of a minimal-Landau-gauge configuration $A \in \Omega$ from the boundary $\partial\Omega$.
- First concrete explanation of why lattice studies do not observe an enhanced ghost propagator in the deep infrared limit.
- First evaluation of the Bose-ghost propagator (of the Gribov-Zwanziger theory).
- First numerical manifestation of BRST-symmetry breaking due to restriction of gauge-configuration space to the Gribov region.
- New analysis and results for Gribov-copy effects: in preparation.

☺ The New Toy: BG/Q

The Rice BlueGene/P was upgraded to BlueGene/Q around March 2015.

Weak and Strong Scaling on BG/Q

V	Nodes	HB	Micro	Gfix	GluonProp	CG
$64^2 \times 32^2$	32	494.9	54.7	0.0044	0.0041	0.0081
$64^3 \times 32$	64	496.3	62.1	0.0049	0.0041	0.0088
64^4	128	496.8	59.2	0.0047	0.0050	0.0084
$64^3 \times 128$	256	499.4	63.0	0.0050	0.0041	0.0090
$64^2 \times 128^2$	512	499.7	56.4	0.0046	0.0042	0.0083
64^4	128	496.8	59.2	0.0047	0.0050	0.0084
64^4	256	256.3	37.9	0.0029	0.0028	0.0055
64^4	512	134.6	27.3	0.0020	0.0018	0.0040
64^4	1024	74.4	22.5	0.0016	0.0012	0.0035
64^4	512	2943.6	218.5	0.0171	0.0179	0.0239

Weak (with 5 different lattice volumes) and strong (with 4 different volumes) scaling: time (in seconds) for 3 different updates of local variables and for the evaluation of the gluon propagator and the time (in seconds) for one conjugate gradient iteration. Link and site variables are SU(2) matrices. The last row is for the BG/P.

Working on a New Code

Combine all our different codes, developed in the last 25 years, in one single code.

Make it possible to choose, at compilation time/running time, among several options:

- BlueGene or Intel machine.
- Dimensionality of the space-time lattice.
- Gauge group.
- Gauge-fixing condition.
- Kinematics for Green's functions.
- Quantities to be evaluated.

V	Nodes	HB	Micro	Gfix	GluonProp	CG
$64^2 \times 32^2$	32	493.2	55.5	0.0071	0.0059	0.0111
$64^3 \times 32$	64	493.9	57.1	0.0071	0.0056	0.0111

THANKS!