LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

QUANTHEP 2024
September 2-5, 2024

CRQIT Center for Research in Quantum Information and Technology

Quantum Technologies and Computation for High Energy Physics

Hamiltonian Simulation of Non-Abelian Gauge Theories Using Loops Strings and Hadrons

Indrakshi Raychowdhury

Birla Institute of Technology and Science Pilani, K K Birla Goa Campus

Classical Computation Era

Change of Paradigm

Quantum Computation Era

Our role

- Identifying the physics problem that would benefit from quantum computation
- Reformulating the problem suitable for quantum computation
- NISQ-era quantum simulation algorithms: analog and digital
- Think beyond NISQ era…

Lattice gauge theory calculations without sign problem: Real time dynamics

Classical Computation Era | **Lattice gauge theory calculations** | Quantum Computation Era

- Requires different theoretical framework.
- Addressed different objectives
- Computational Methods are entirely different.

Ultimate goal: performing LATTICE-QCD calculations using Quantum Computer

Intermediate steps:

- Suitable development and choice of framework.
- Suitable choice of variables/basis.
- Algorithm development for various tasks- classical/quantum/hybrid.
- Quantum information theoretic understanding - connection to physics of QCD
- Quantum advantage - knowledge generation in fundamental laws of nature.

Ultimate goal: performing LATTICE-QCD calculations using Quantum Computer

Current Efforts: For simpler models such as Schwinger model, discrete gauge groups, low dimensional SU(2)/SU(3) gauge theory

Intermediate steps:

- Suitable development and choice of framework. ✓
- Suitable choice of variables/basis.
- Algorithm development for various tasks- classical/quantum/hybrid. ✓
- Quantum information theoretic understanding - connection to physics of QCD
- Quantum advantage - knowledge generation in fundamental laws of nature.

Ultimate goal: performing LATTICE-QCD calculations using Quantum Computer

Current Efforts: For arbitrary dimensional SU(2)/SU(3) gauge theories

Intermediate steps:

- Suitable development and choice of framework. ✓
- Suitable choice of variables/basis. ✓
- Algorithm development for various tasks- classical/quantum/hybrid. ✓
- Quantum information theoretic understanding - connection to physics of QCD ✓
- Quantum advantage - knowledge generation in fundamental laws of nature.

Framework: Hamiltonian Formalism

PHYSICAL REVIEW D VOLUME 11, NUMBER 2 15 JANUARY 1975

Hamiltonian formulation of Wilson's lattice gauge theories

John Kogut*

Laboratory of Nuclear Studies, Cornell University, Ithaca, New York 14853

Leonard Susskind†

Belfer Graduate School of Science, Yeshiva University, New York, New York
and Tel Aviv University, Ramat Aviv, Israel
and Laboratory of Nuclear Studies, Cornell University, Ithaca, New York

(Received 9 July 1974)

Wilson's lattice gauge model is presented as a canonical Hamiltonian theory. The structure of the model is reduced to the interactions of an infinite collection of coupled rigid rotators. The gauge-invariant configuration space consists of a collection of strings with quarks at their ends. The strings are lines of non-Abelian electric flux. In the strong-coupling limit the dynamics is best described in terms of these strings. Quark confinement is a result of the inability to break a string without producing a pair.

Gauge Theories are always Difficult !

Hamiltonian framework and the principle of gauge invariance:

a set of local constraints to satisfy.

Tasks:

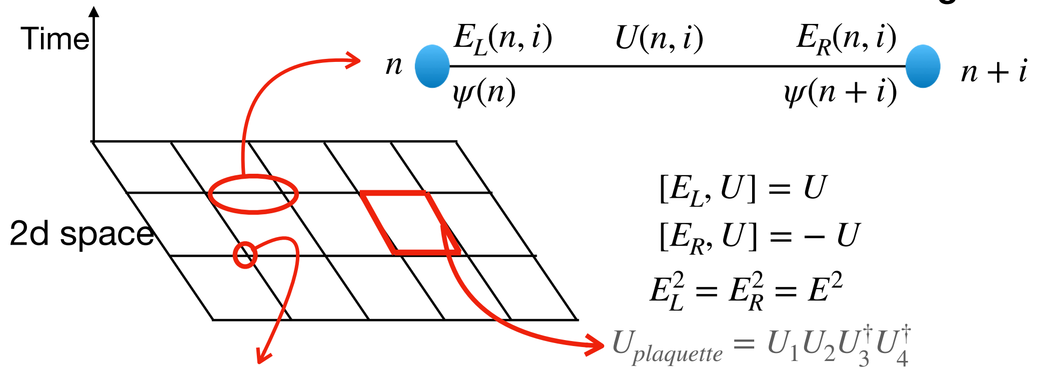
Choice of a basis: either a electric/strong coupling basis or a group element basis.

Dealing with gauge redundancy: via gauge fixing / finding gauge invariant solution.

Qubitization and Quantum computation/simulation of Hamiltonian dynamics:
in NISQ devices and beyond - benchmarking the quantum computation by classical computation

Framework: Hamiltonian Formalism

Kogut-Susskind '74



$$[E_L, U] = U$$
$$[E_R, U] = -U$$
$$E_L^2 = E_R^2 = E^2$$
$$U_{plaquette} = U_1 U_2 U_3^\dagger U_4^\dagger$$

Gauss' law constraint:

$$G(n)\,|\Psi_{phys}\rangle = 0$$

$$[H, G(n)] = 0 \qquad \forall n$$

$$G(n) = \sum_I \left[E_L(n,I) - E_R(n-I,I)\right] - \rho(n)$$

$$H = H_E + H_M + H_I + H_B$$

$$\frac{g^2 a}{2}\sum_{n,I} E^2(n,I)$$

$$m\sum (-1)^n\ \psi^\dagger(n)\psi(n)$$

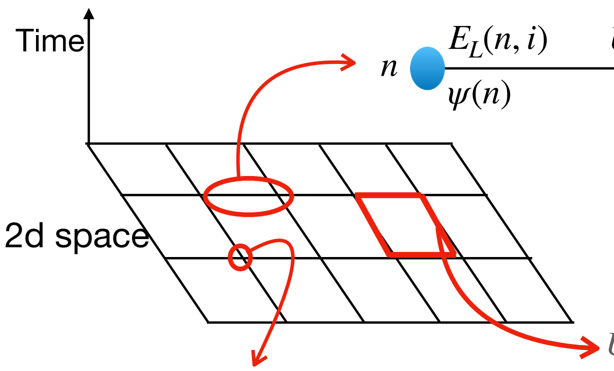
Staggered fermion

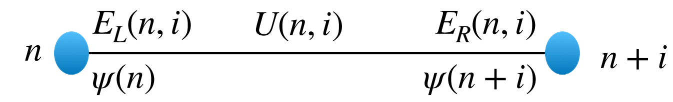
$$\frac{1}{2a}\sum_{n,I}(-1)^n\ \psi^\dagger(n)U(n,I)\psi(n+I)$$

$$\frac{2a}{g^2}\sum_{plaquettes}\left[\mathrm{Tr}U_{plaquette} + h.c\right]$$

Framework: Hamiltonian Formalism

Kogut-Susskind ‘74





$$[E_L, U] = U$$

$$[E_R, U] = -U$$

$$E_L^2 = E_R^2 = E^2$$

$$U_{plaquette} = U_1 U_2 U_3^\dagger U_4^\dagger$$

Gauss’ law constraint:

$$G(n)\,|\,\Psi_{phys}\rangle = 0$$

$$[H, G(n)] = 0 \quad \forall n$$

$$G(n) = \sum_I \left[E_L(n,I) - E_R(n-I,I)\right] - \rho(n)$$

$$H = H_E + H_M + H_I + H_B$$

$$H_E: \quad \frac{g^2 a}{2}\sum_{n,I} E^2(n,I)$$

$$H_M: \quad m\sum (-1)^n\,\psi^\dagger(n)\psi(n)$$

Staggered fermion

$$H_I: \quad \frac{1}{2a}\sum_{n,I} (-1)^n\,\psi^\dagger(n)U(n,I)\psi(n+I)$$

$$H_B: \quad \frac{2a}{g^2}\sum_{plaquettes}\left[\mathrm{Tr}U_{plaquette} + h.c\right]$$

U(1): $U(n,I) = e^{i\theta(n,I)}$

Schwinger Model : U(1) in 1+1d, H_B term absent

SU(2):

$$E \to E^{\mathrm{a}}, \quad \mathrm{a} = 1,2,3$$

$$U \to U_{\alpha\beta}, \quad \alpha,\beta = 1,2$$

$$\psi \to \psi_\alpha, \quad \alpha = 1,2$$

$$G(n) \to G^{\mathrm{a}}(n) = \sum_I \left[E_L^{\mathrm{a}}(n,I) + E_R^{\mathrm{a}}(n-I,I)\right] + \psi(n)^\dagger \frac{\sigma^{\mathrm{a}}}{2}\psi(n)$$

SU(3): $\mathrm{a} = 1,2,3,\ldots,8.$

A promising solution: Loop-string-hadron (LSH) framework

Features:

LSH occupation number basis: a strong coupling basis.

Non-Abelian gauge redundancy: solved analytically.

LSH basis states are explicitly annihilated by the onsite Gauss law generators.

A physical state is 1-sparse in the LSH occupation basis

Qubitization: with Bosonic degrees of freedom

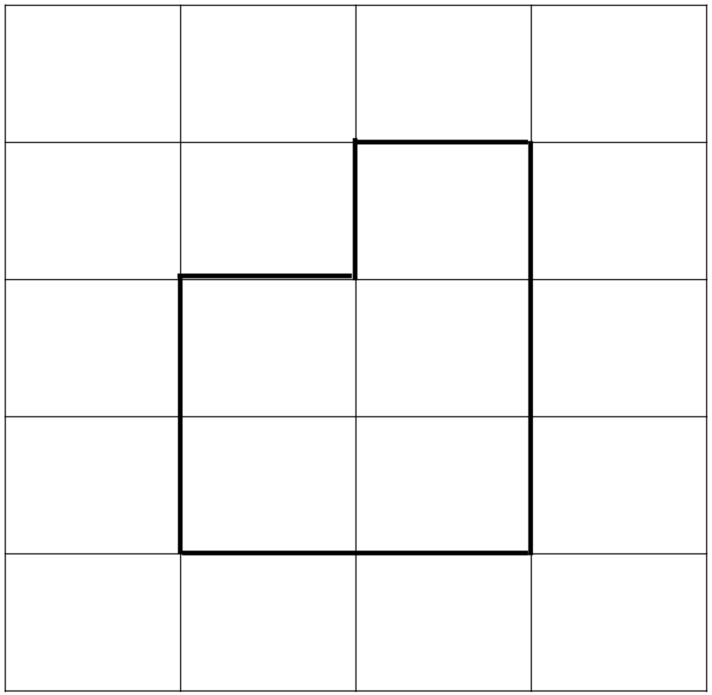
- allows analyzing and minimizing cut-off effect.

Hamiltonian dynamics: Spectum is identical to Kogut-Susskind Hamiltonian

Exact diagonalization, Tensor network calculations;

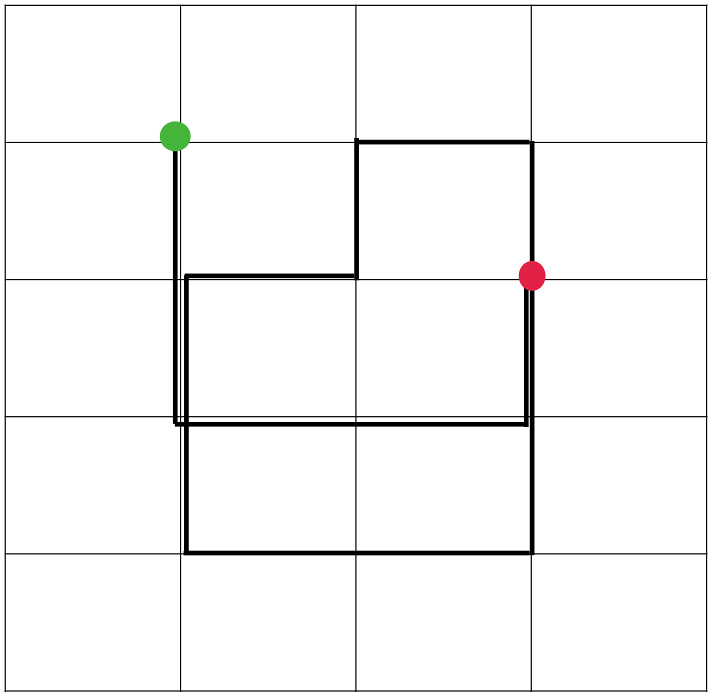
algorithm for analog and digital quantum hardware.

Loops-Strings-Hadrons : SU(2)



Wilson loops

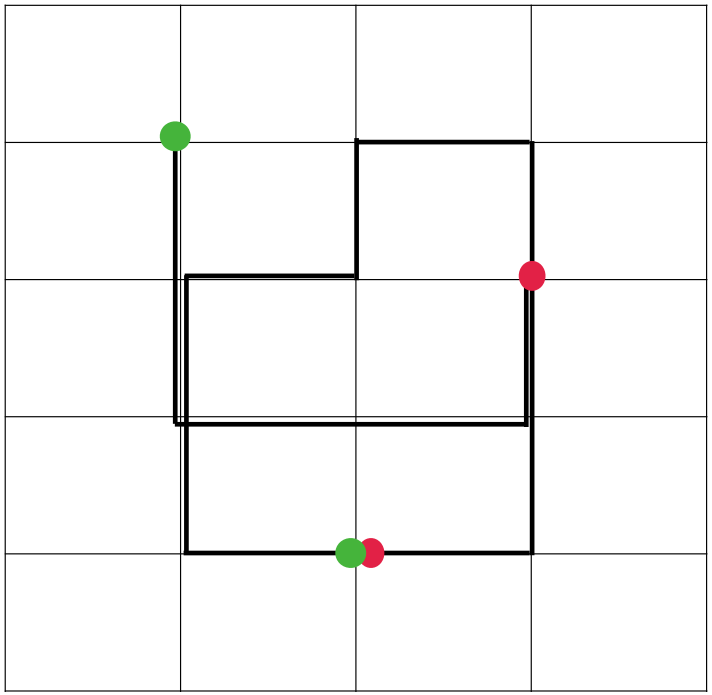
Loops-Strings-Hadrons : SU(2)



Wilson loops

Strings/mesons

Loops-Strings-Hadrons : SU(2)

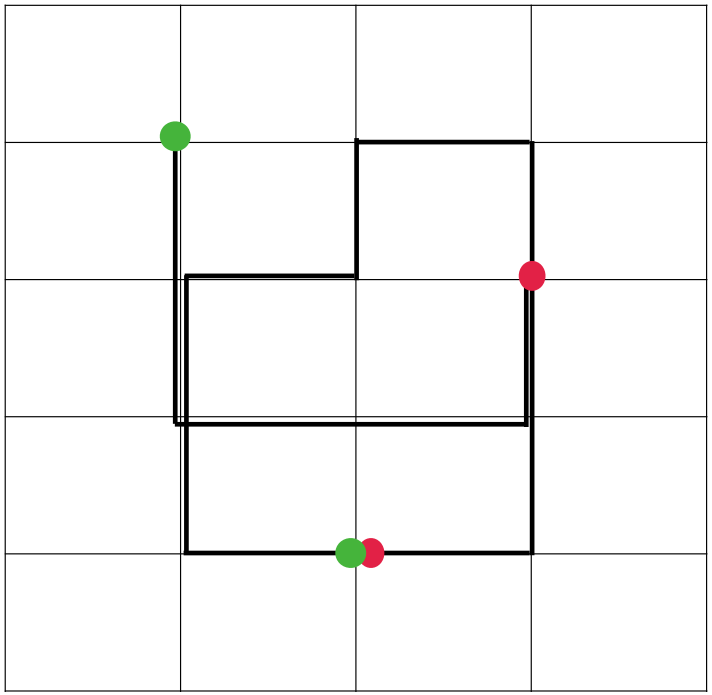


Wilson loops

Strings/mesons

Hadrons

Loops-Strings-Hadrons : SU(2)



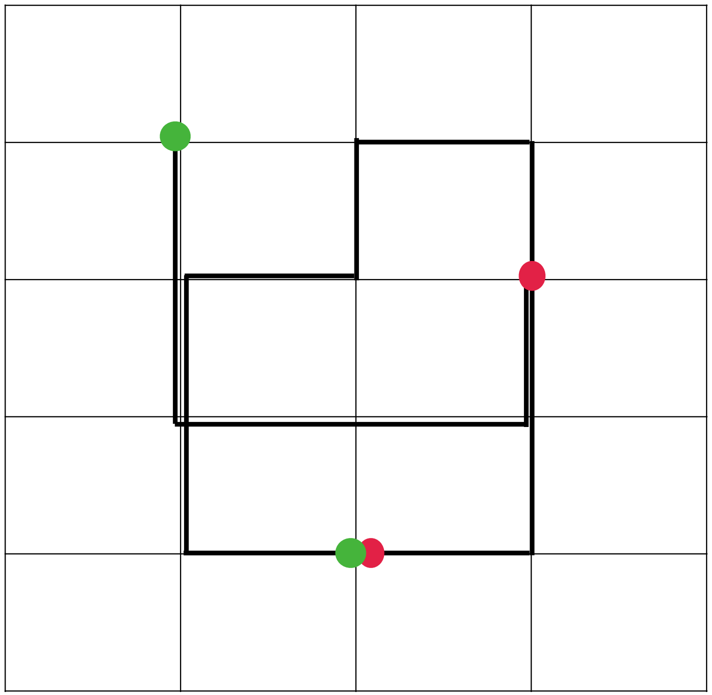
Wilson loops

Strings

Hadrons

Loops-Strings-Hadrons : SU(2) in 1+1 d

Loops-Strings-Hadrons : SU(2)



Wilson loops

Strings

Hadrons

Gauge invariance leads to non-locality

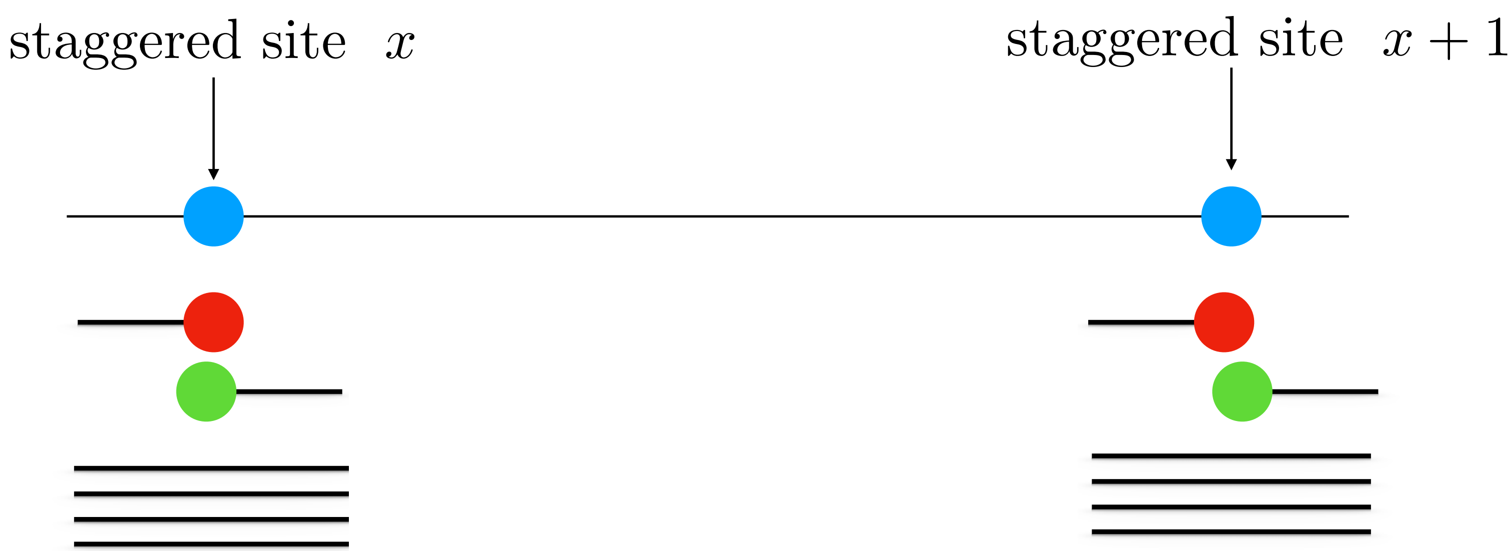
On site snapshots of gauge invariant configurations

LSH basis

Loops-Strings-Hadrons : SU(2) in 1+1 d

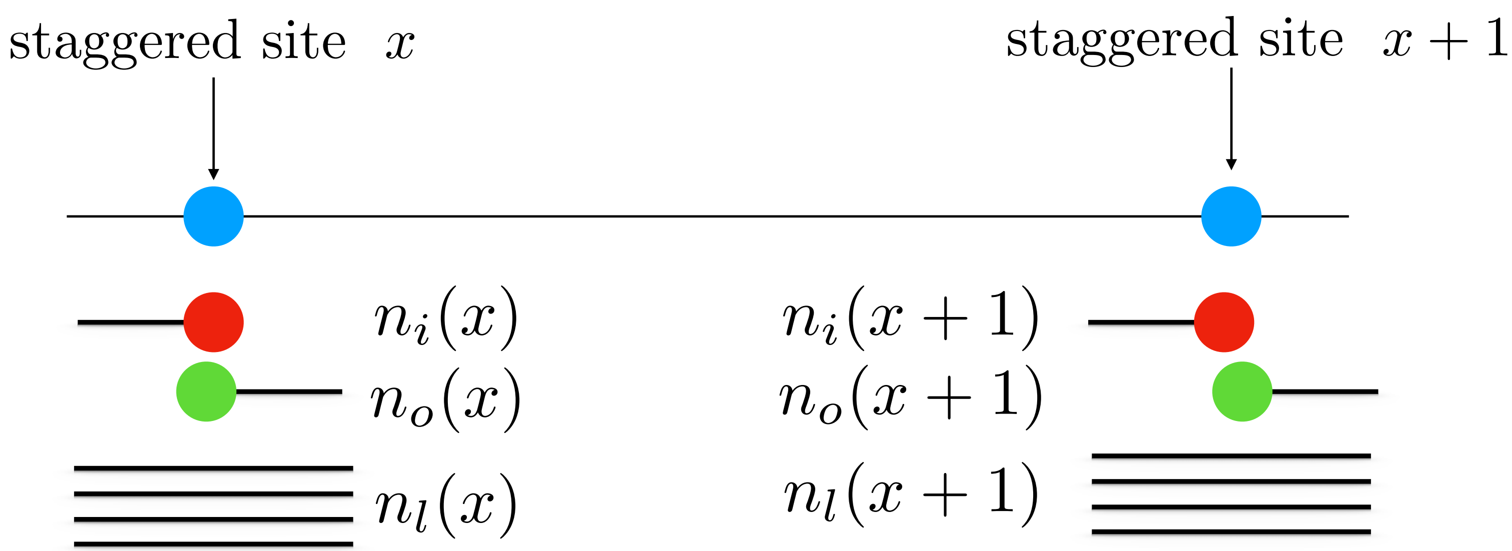
Loops-Strings-Hadrons : SU(2) in 1+1 d

On site snapshots of gauge invariant configurations



Loops-Strings-Hadrons : SU(2) in 1+1 d

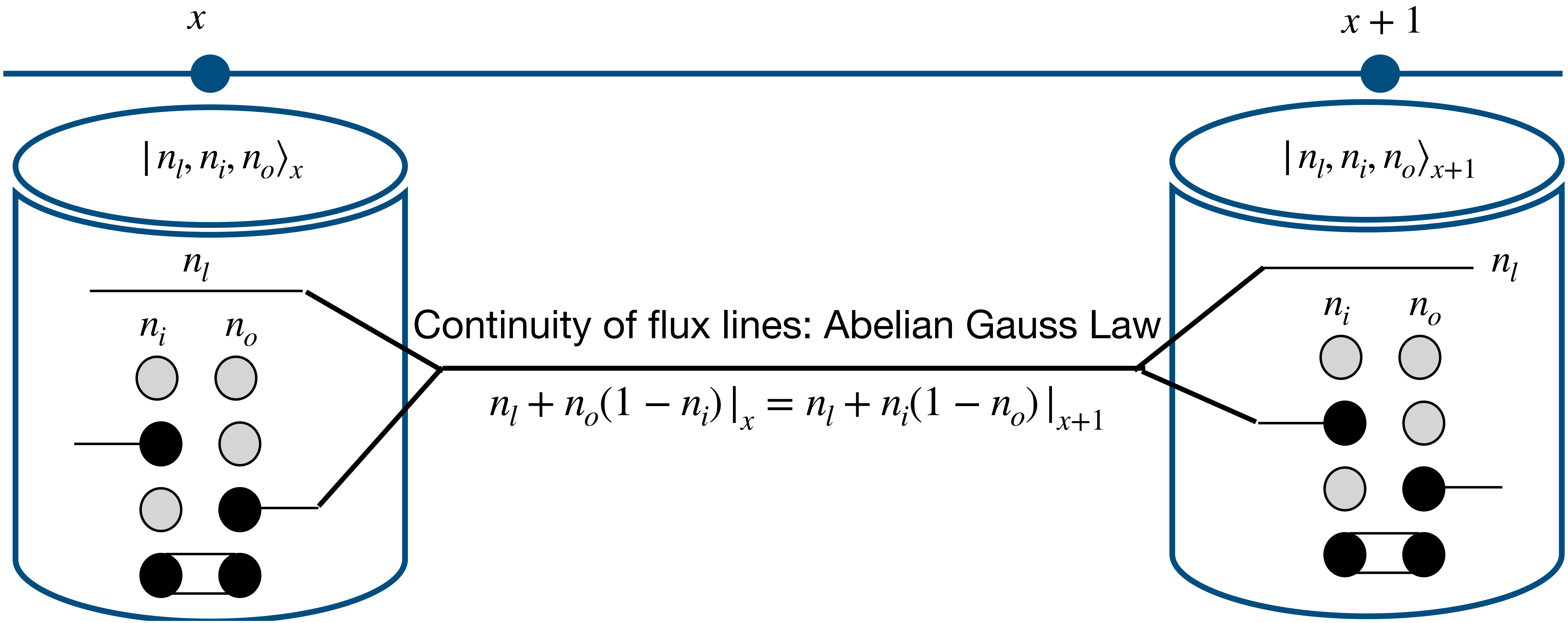
On site snapshots of gauge invariant configurations



Loops-Strings-Hadrons : SU(2) in 1+1 d

Global LSH states are constructed by imposing Abelian Gauss Law constraints

Non-locality remains crucial, but is then care by Abelian constraints



Hamiltonian, describing dynamics of loops, strings and hadrons.

$$H^{(\mathrm{LSH})} = H_I^{(\mathrm{LSH})} + H_E^{(\mathrm{LSH})} + H_M^{(\mathrm{LSH})}$$

$$H_I^{(\mathrm{LSH})} = \frac{1}{2a}\sum_n \Bigg\{ \frac{1}{\sqrt{\hat{n}_l(x) + \hat{n}_o(x)(1-\hat{n}_i(x)) + 1}} \times \left[\hat{S}_o^{++}(x)\hat{S}_i^{+-}(x+1) + \hat{S}_o^{+-}(x)\hat{S}_i^{--}(x+1)\right] \times \frac{1}{\sqrt{\hat{n}_l(x+1) + \hat{n}_i(x+1)(1-\hat{n}_o(x+1)) + 1}} + \mathrm{h.c.} \Bigg\},$$

$$H_E^{(\mathrm{LSH})} = \frac{g^2 a}{2}\sum_n \left[\frac{\hat{n}_l(x) + \hat{n}_o(x)(1-\hat{n}_i(x))}{2} \times \left(\frac{\hat{n}_l(x) + \hat{n}_o(x)(1-\hat{n}_i(x))}{2} + 1 \right) \right],$$

$$H_M^{(\mathrm{LSH})} = m\sum_n (-1)^x (\hat{n}_i(x) + \hat{n}_o(x)),$$

$$\hat{S}_o^{++} = \hat{\chi}_o^{+}(\lambda^+)^{\hat{n}_i}\sqrt{\hat{n}_l + 2 - \hat{n}_i},$$
$$\hat{S}_o^{--} = \hat{\chi}_o^{-}(\lambda^-)^{\hat{n}_i}\sqrt{\hat{n}_l + 2(1 - \hat{n}_i)},$$
$$\hat{S}_o^{+-} = \hat{\chi}_i^{+}(\lambda^-)^{1-\hat{n}_o}\sqrt{\hat{n}_l + 2\hat{n}_o},$$
$$\hat{S}_o^{-+} = \hat{\chi}_i^{-}(\lambda^+)^{1-\hat{n}_o}\sqrt{\hat{n}_l + 1 + \hat{n}_o},$$

$$\hat{S}_i^{+-} = \hat{\chi}_o^{-}(\lambda^+)^{1-\hat{n}_i}\sqrt{\hat{n}_l + 1 + \hat{n}_i},$$
$$\hat{S}_i^{-+} = \hat{\chi}_o^{+}(\lambda^-)^{1-\hat{n}_i}\sqrt{\hat{n}_l + 2\hat{n}_i},$$
$$\hat{S}_i^{--} = \hat{\chi}_i^{-}(\lambda^-)^{\hat{n}_o}\sqrt{\hat{n}_l + 2(1 - \hat{n}_o)},$$
$$\hat{S}_i^{++} = \hat{\chi}_i^{+}(\lambda^+)^{\hat{n}_o}\sqrt{\hat{n}_l + 2 - \hat{n}_o}.$$

The strong-coupling vacuum of the LSH Hamiltonian is given by

$$n_l(x) = 0, \text{ for all } x,$$
$$n_i(x) = 0,\ n_o(x) = 0, \text{ for } x \text{ even},$$
$$n_i(x) = 1,\ n_o(x) = 1, \text{ for } x \text{ odd}.$$

Collaborators:

Jesse Stryker

Spectrum is identical to Kogut Susskind Hamiltonian

Loops-Strings-Hadrons Framework

Local non-Abelian constraints are solved analytically by construction: LSH formalism is manifestly SU(2)/SU(3) invariant

Local constraint structure: U(1), always as in 1d even for higher dimensional LSH

↓

Global symmetry structure: Multiple U(1) and discrete symmetries

Loops-Strings-Hadrons Framework

Local non-Abelian constraints are solved analytically by construction: LSH formalism is manifestly SU(2)/SU(3) invariant

Local constraint structure: U(1), always as in 1d even for higher dimensional LSH

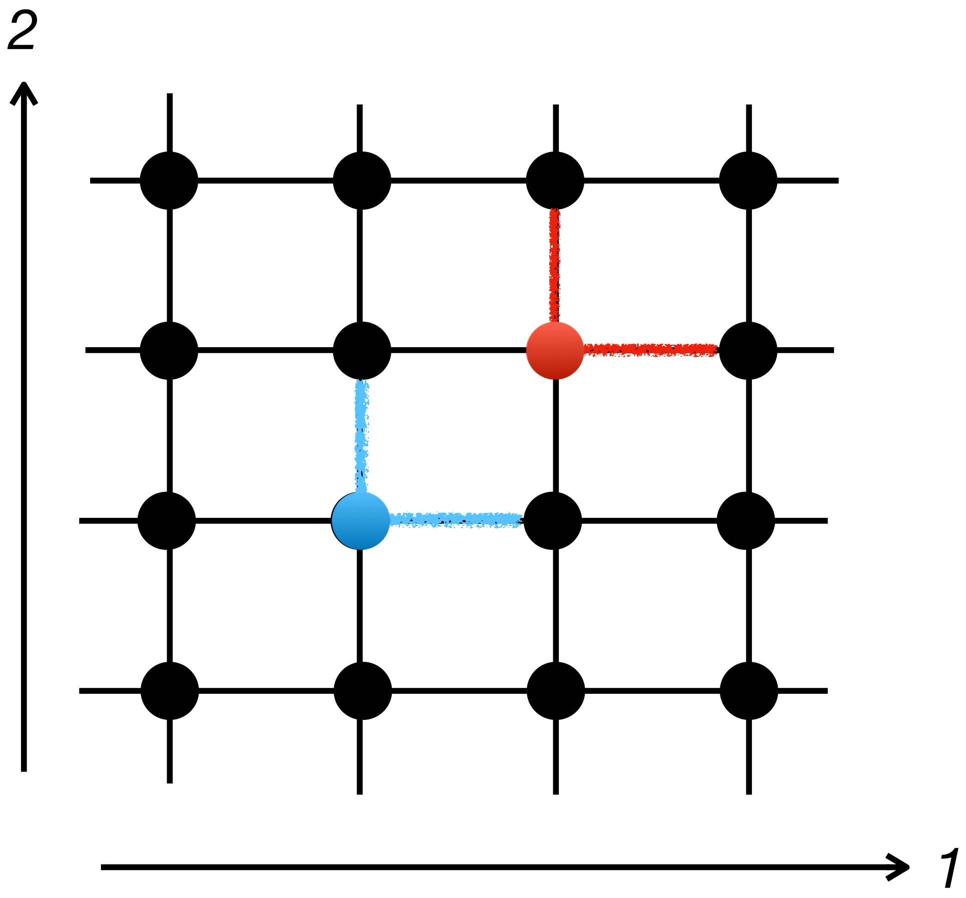
↓

Global symmetry structure: Multiple U(1) and discrete symmetries

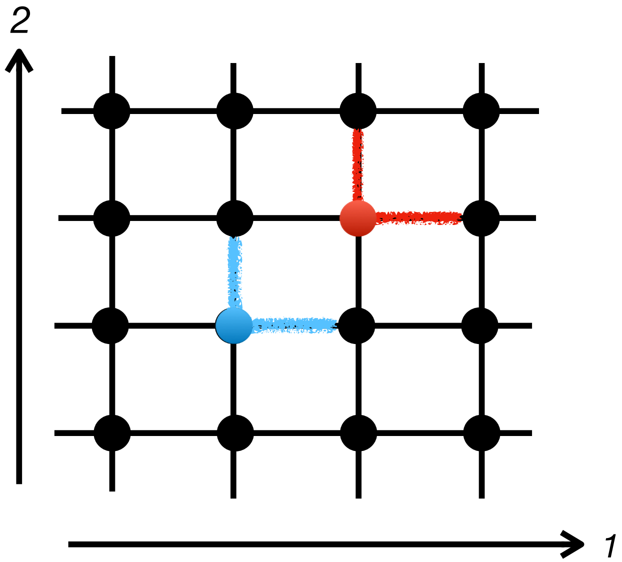
Useful for both theoretical analysis and classical/quantum computation

Underlying complicated route via prepotentials/Schwinger bosons can be bypasses for application/implementation

SU(2) LSH framework in $d > 1$

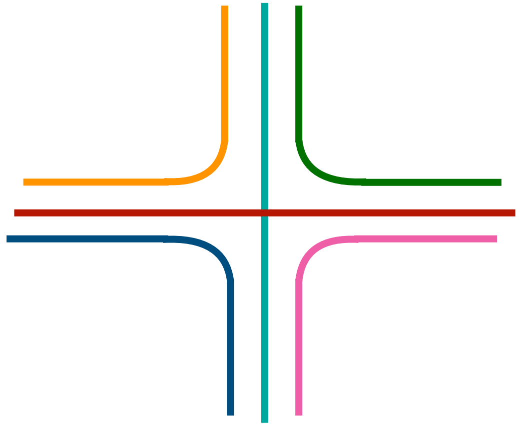


SU(2) LSH framework in $d = 2 + 1$



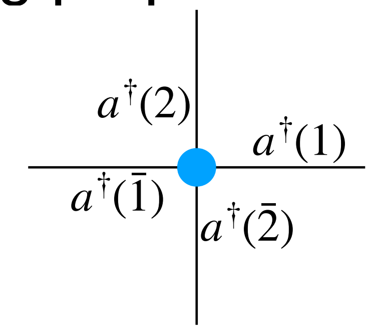
Focussing at a site for pure gauge theory

On-site contribution from Wilson loops:



Overcomplete loop basis

Underlying prepotential construction:



Local Loop Operators

$$\mathcal{L}^{++}_{ij} = \epsilon^{\alpha\beta} a^\dagger_\alpha(i) a^\dagger_\beta(j)$$

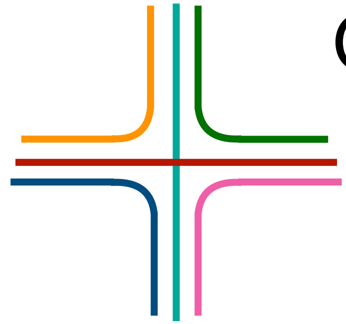
Local loop state:

$$|\, l_{12}, l_{1\bar{1}} l_{1\bar{2}}, l_{2\bar{1}}, l_{2\bar{2}}, l_{\bar{1}\bar{2}} \rangle$$

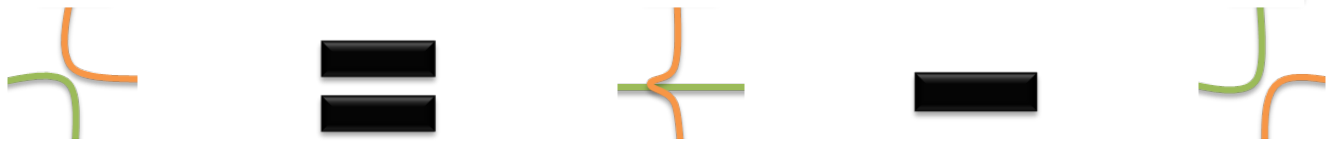
$$\equiv \prod_{ij} \left(\mathcal{L}^{++}_{ij} \right)^{l_{ij}} |0\rangle$$

SU(2) LSH framework in $d = 2 + 1$

Overcomplete basis



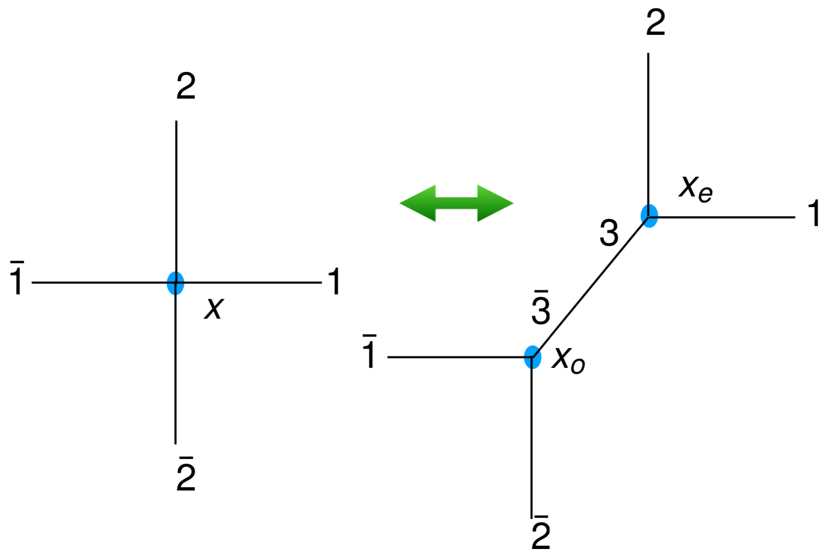
3 physical d.o.f = 6 (local loop quantum numbers in 2d)
- 2(Abelian Gauss' law constraint along 2 link directions)
-1 (**Mandelstam constraint**)



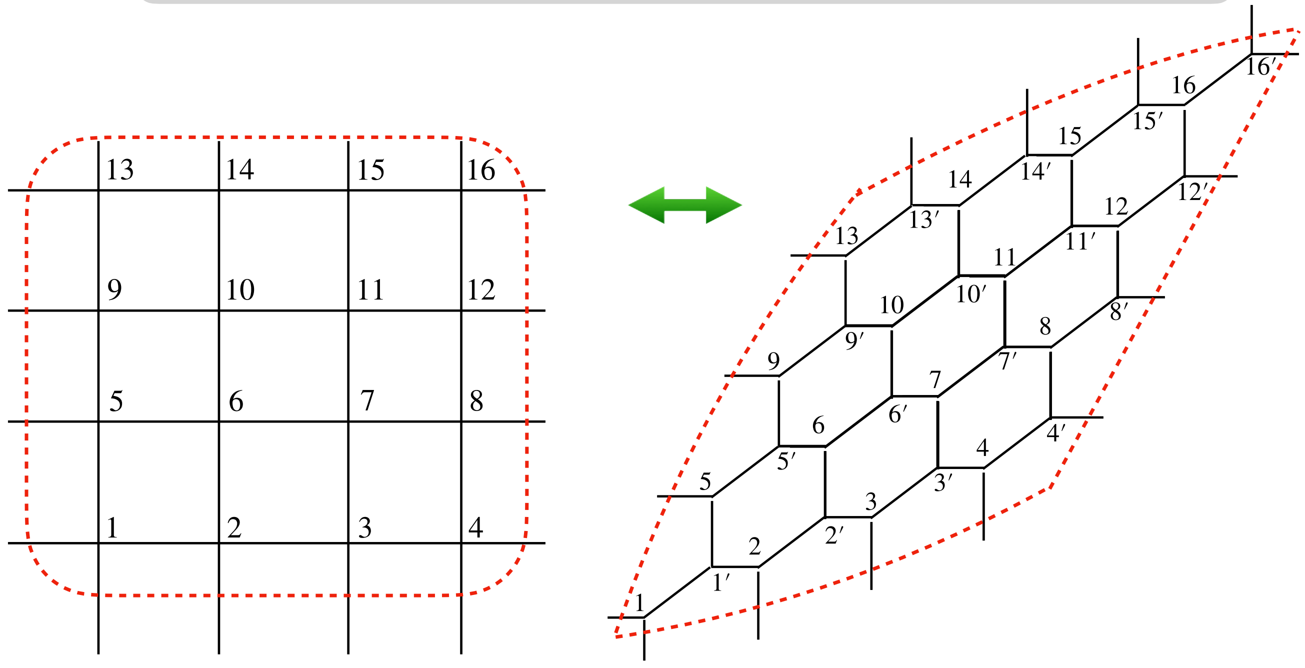
Non-linear constraints, become increasingly complicated with increasing dimensions

SU(2) LSH framework in $d = 2 + 1$

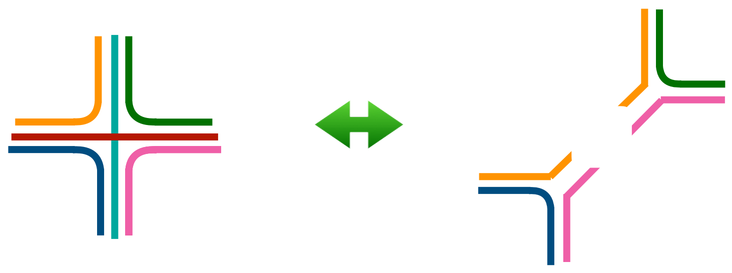
Solution of Mandelstam constraint via a virtual point splitting scheme in pre potential framework

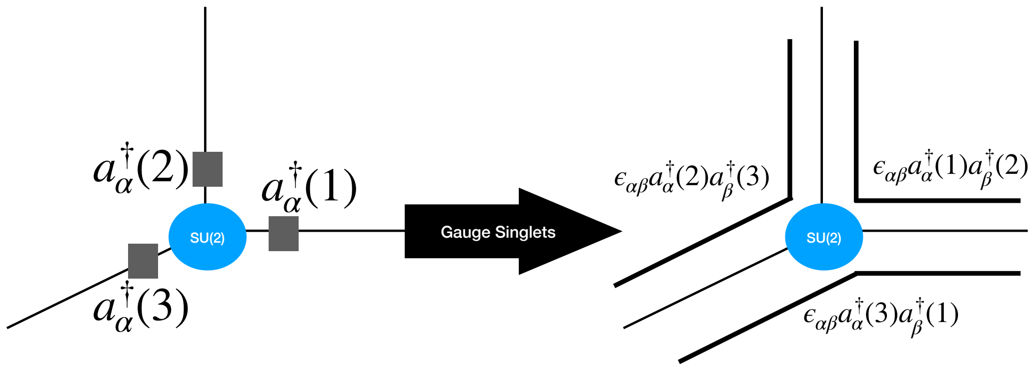


2-d LSH on square lattice is effectively on hexagonal lattice



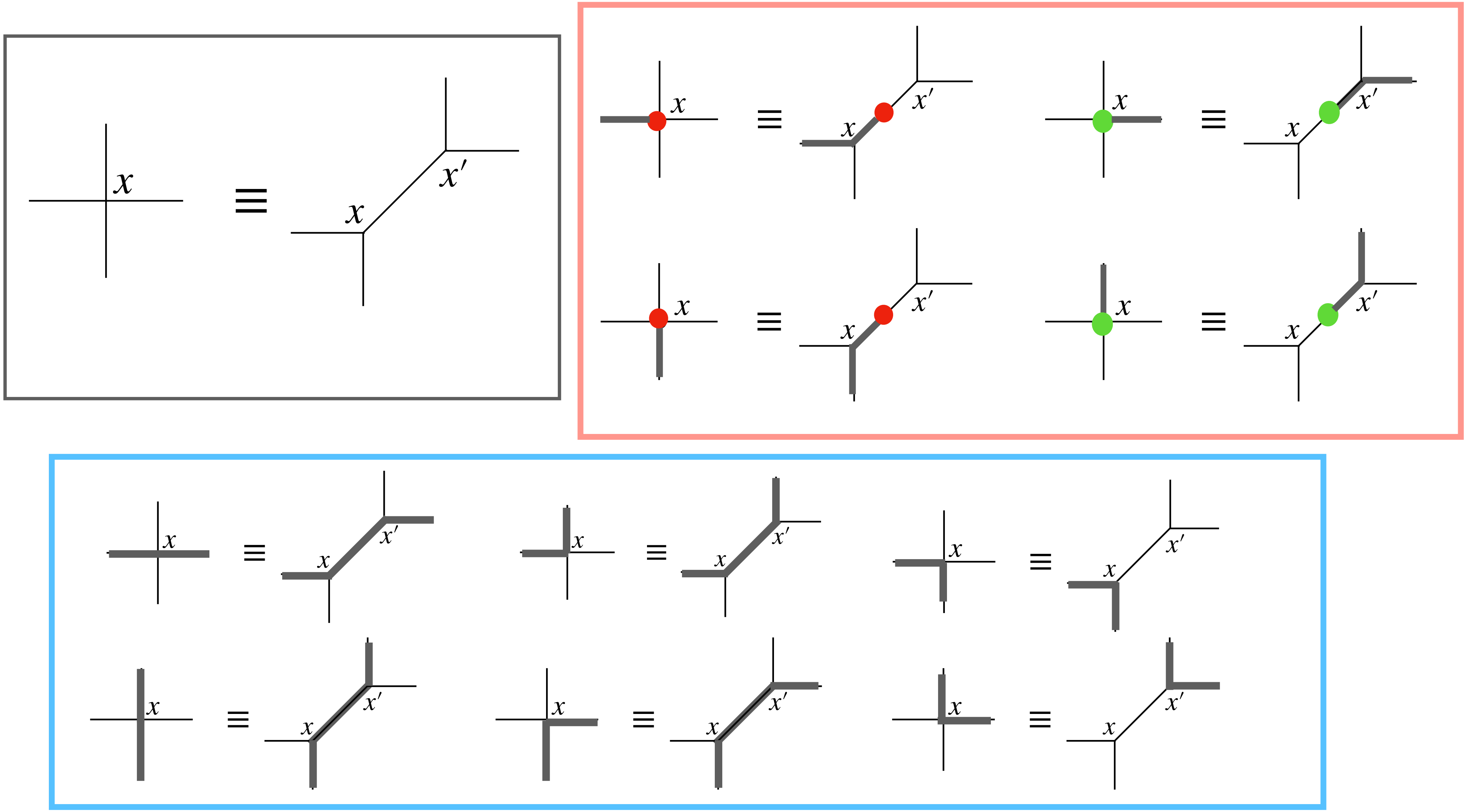
SU(2) LSH framework in $d = 2 + 1$





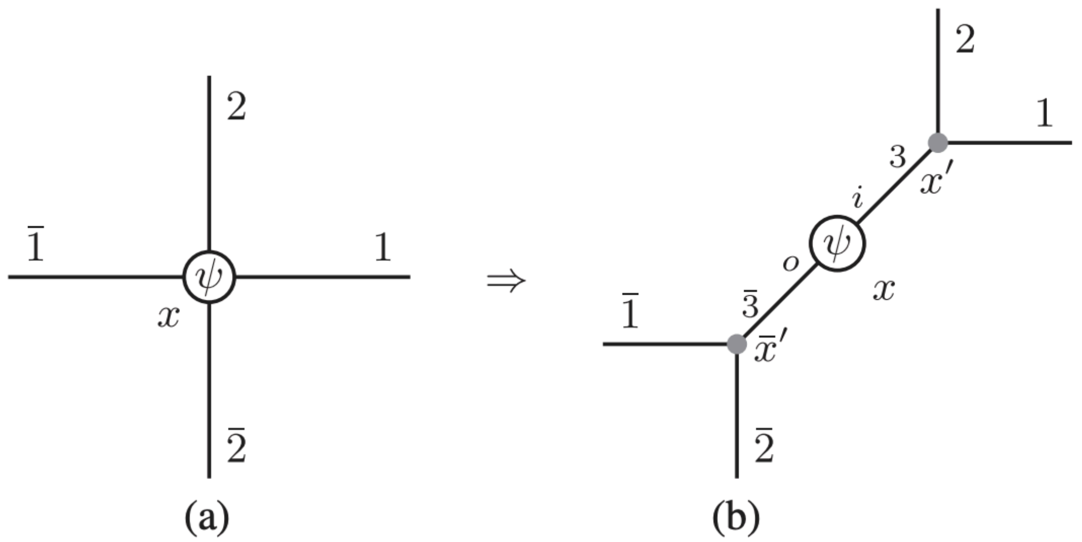
3 physical d.o.f = 2 x 3 (local loop quantum numbers in 2d)
- 3(Abelian Gauss' law constraint)
+ **0** (**Mandelstam constraint**)

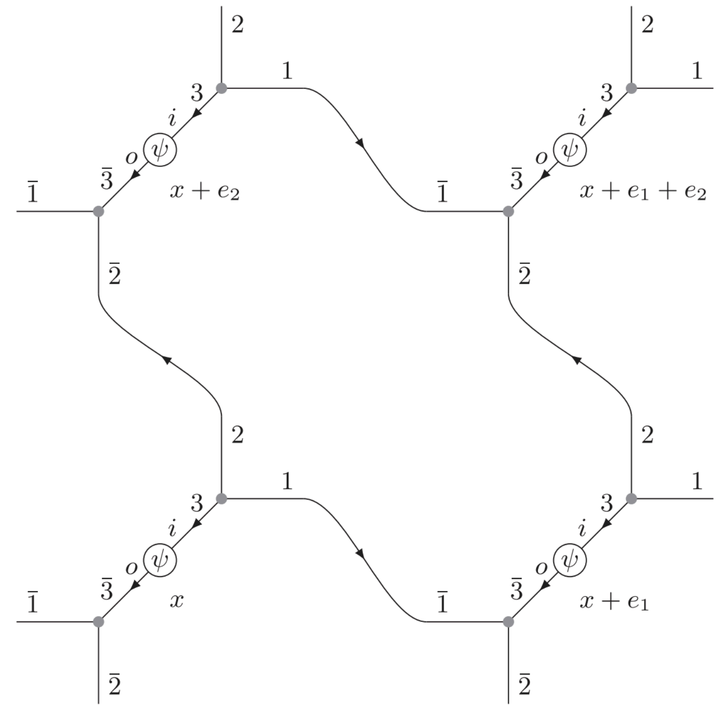
Generalized for arbitrary dimensions!
Generalized to include matter!



x
≡
x
x′

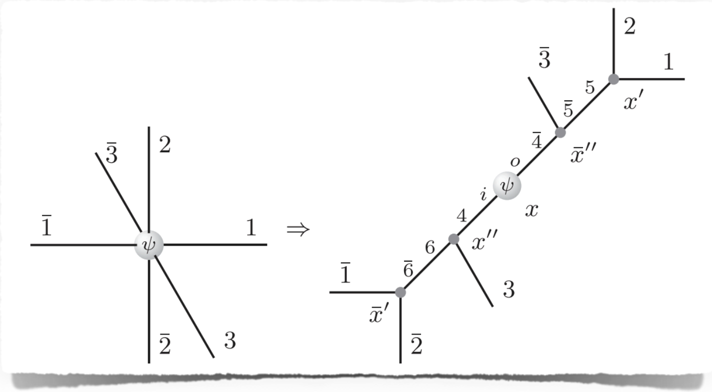
SU(2) LSH Formalism: 2+1 d





Matter-Gauge interactions
are same as in 1d

SU(2) LSH Formalism: 3+1 d



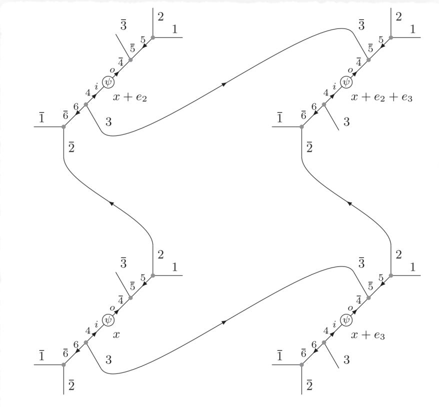


FIG. 8. Connectivity of a *yz*-plaquette in three dimensions.

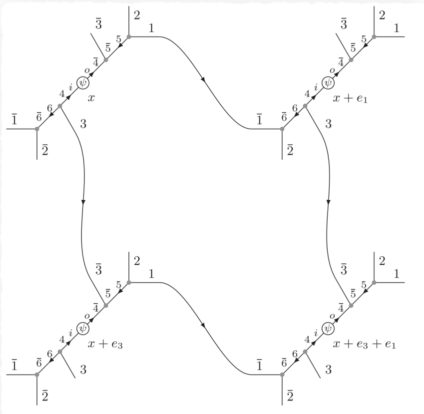


FIG. 9. Connectivity of a *zx*-plaquette in three dimensions.

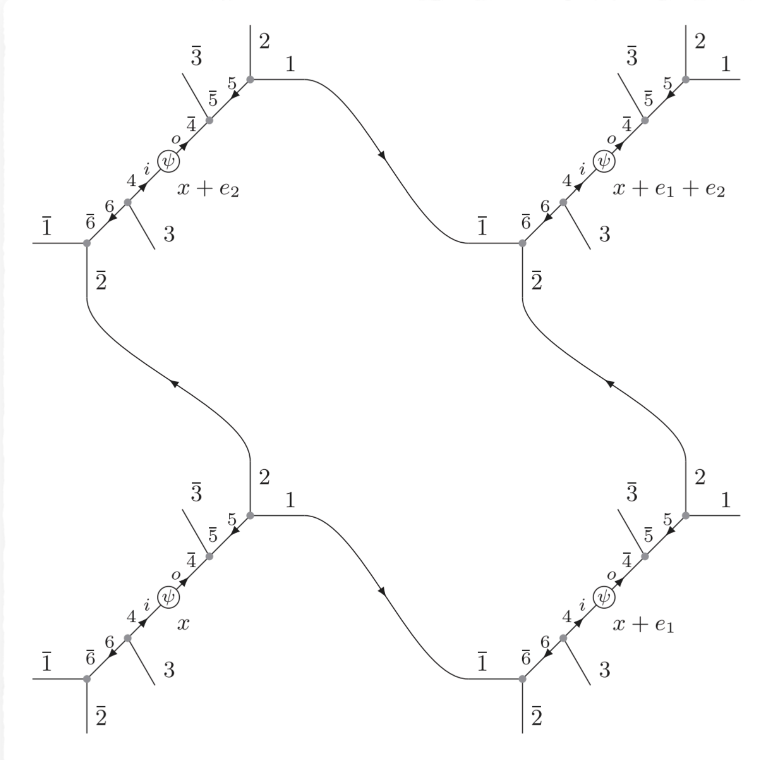
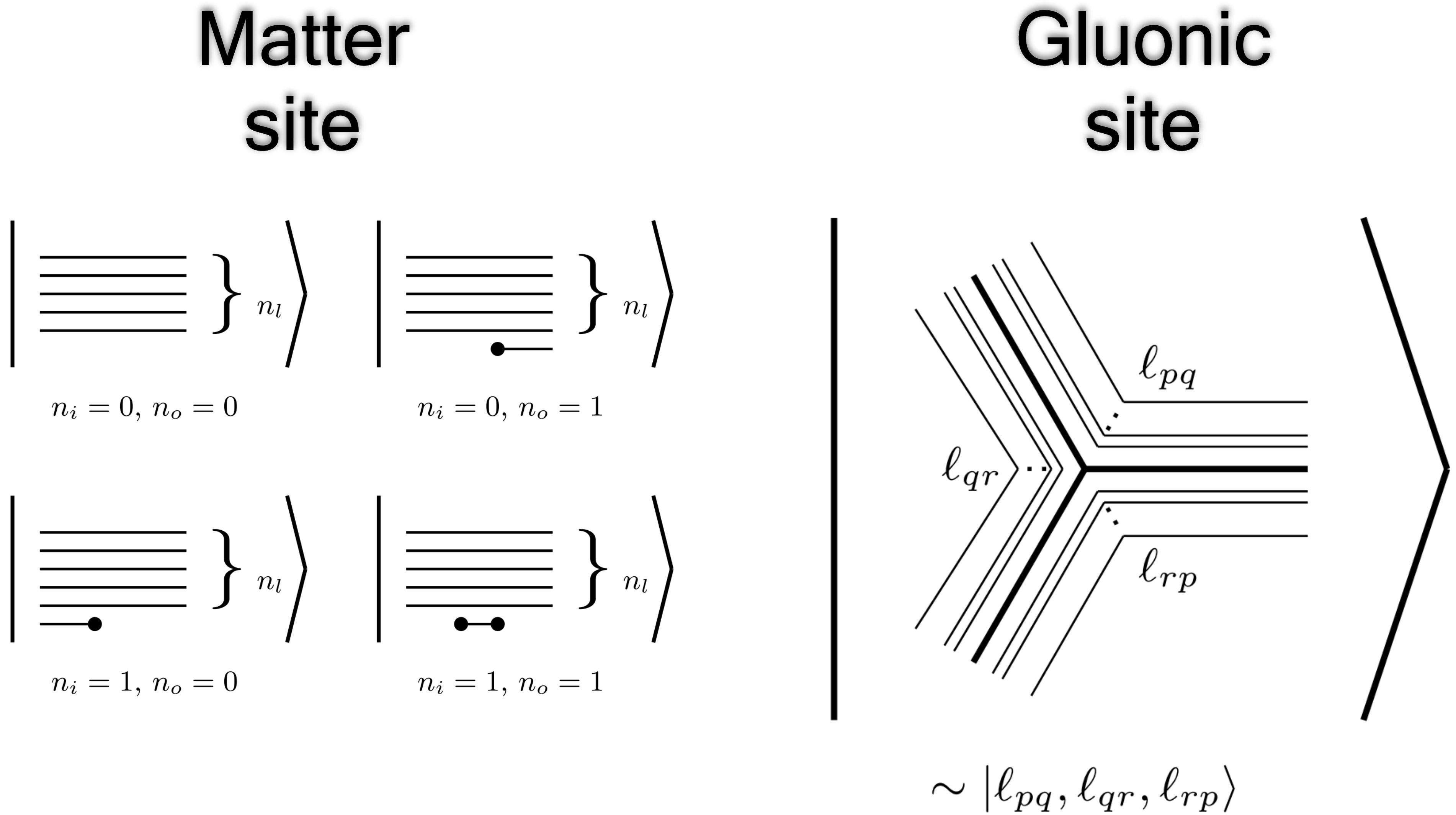


FIG. 7. Connectivity of a *xy*-plaquette in three dimensions.

- Matter-Gauge interactions are same as in 1+1d
- Pure gauge interactions are same as in 2+1d

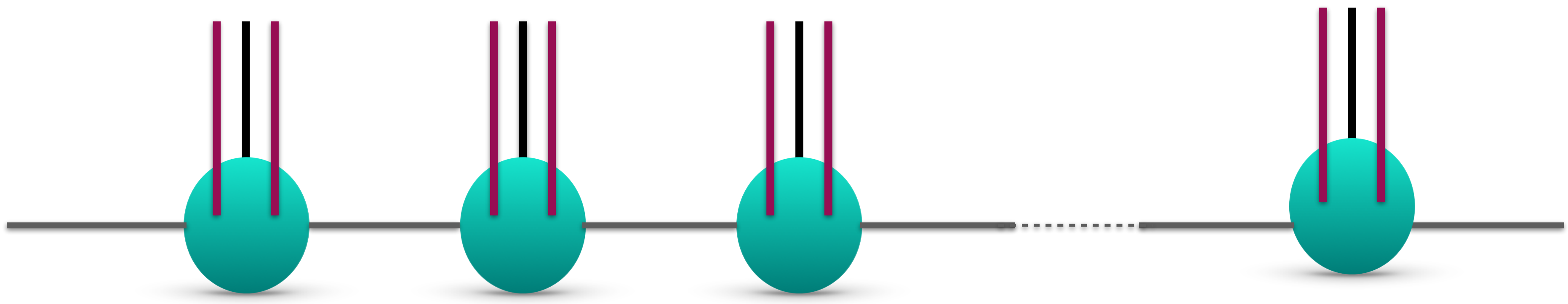


Matter site
n_l
$n_i = 0,\ n_o = 0$
$n_i = 0,\ n_o = 1$
$n_i = 1,\ n_o = 0$
$n_i = 1,\ n_o = 1$
Gluonic site
ℓ_{pq}
ℓ_{qr}
ℓ_{rp}
$\sim |\ell_{pq}, \ell_{qr}, \ell_{rp}\rangle$

Application of the SU(2) LSH framework

Tensor network calculations for non-Abelian gauge theories

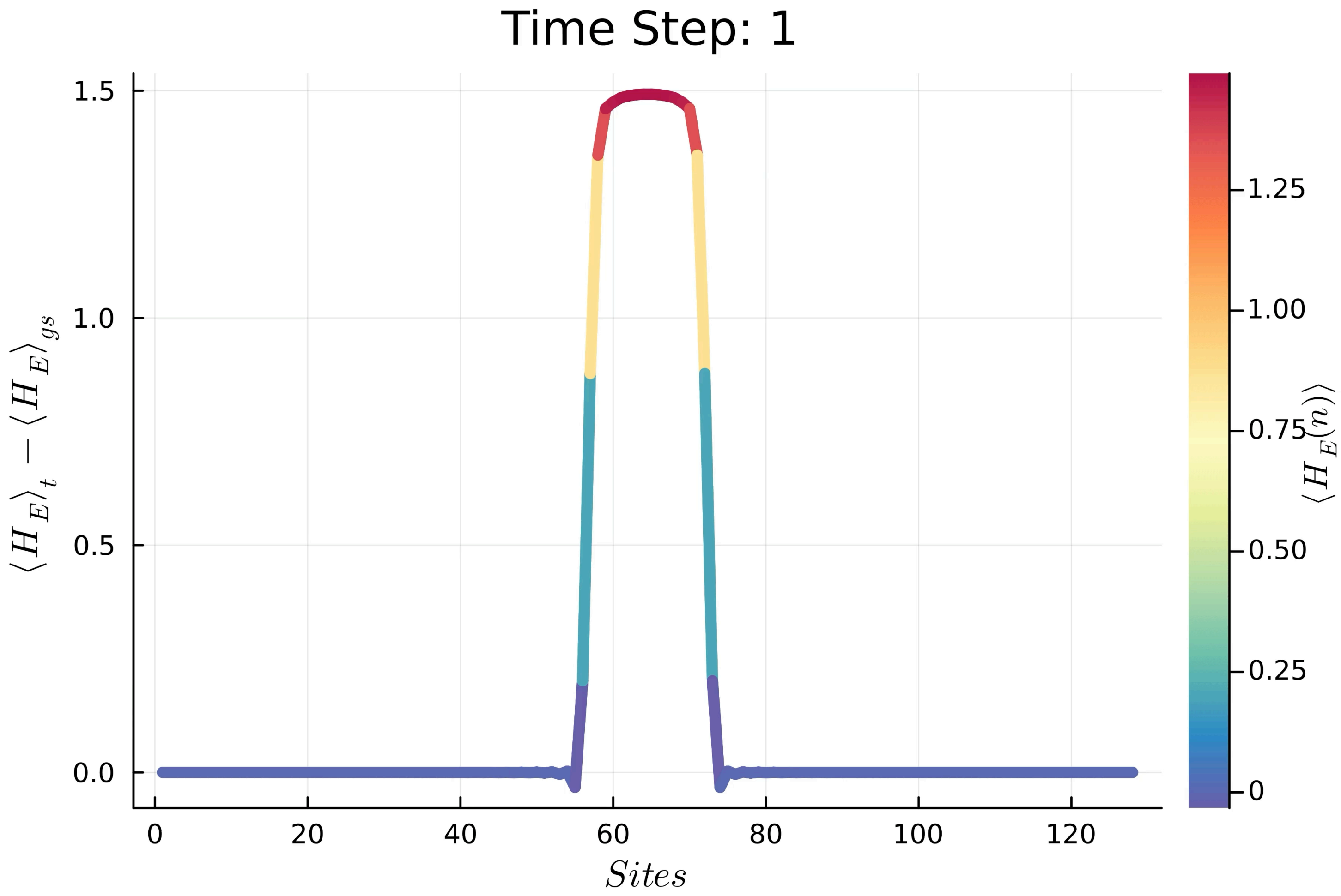
Matrix Product State Ansatz for LSH in one spatial dimension



On-site tensor with three physical indices:
1 bosonic and 2 fermionic

MPS Calculations using LSH framework

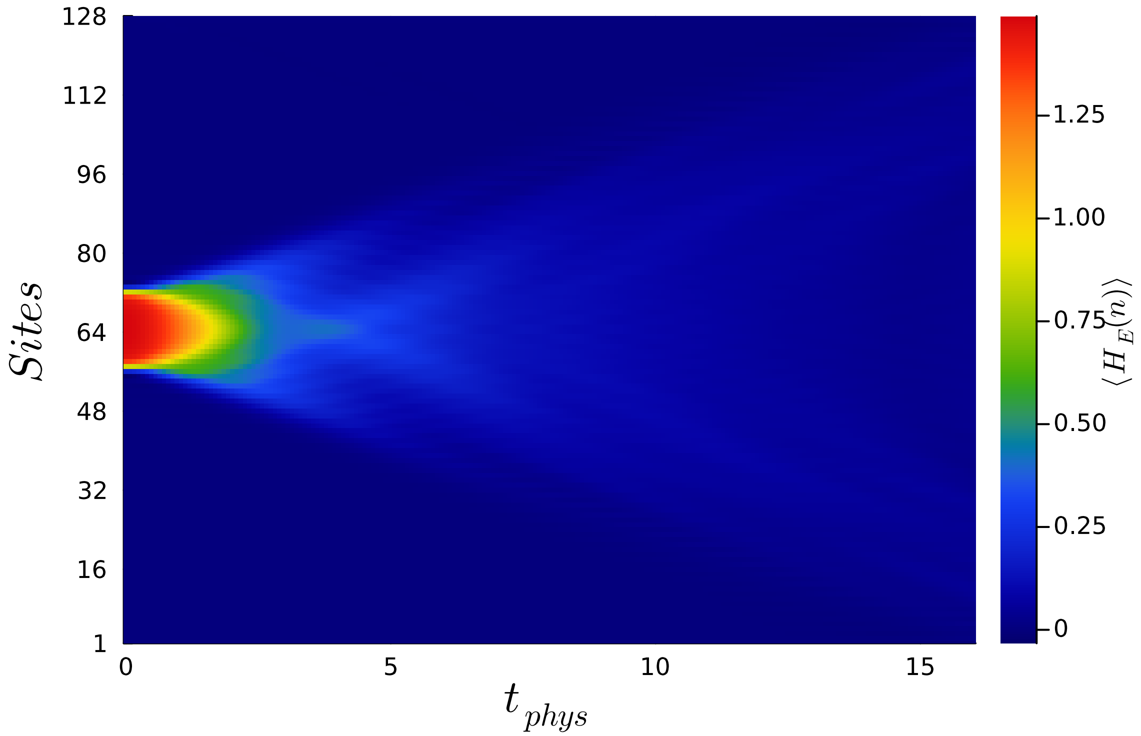
Time-evolution of a string state on the interacting vacuum

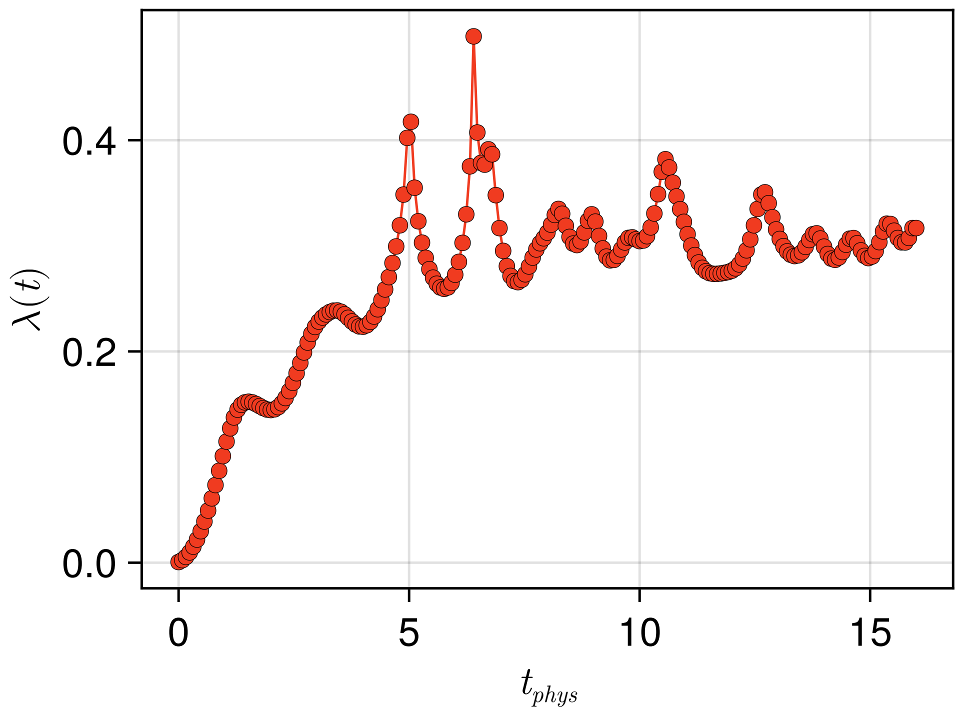


MPS Calculations using LSH framework

MPS preparation of interacting vacuum

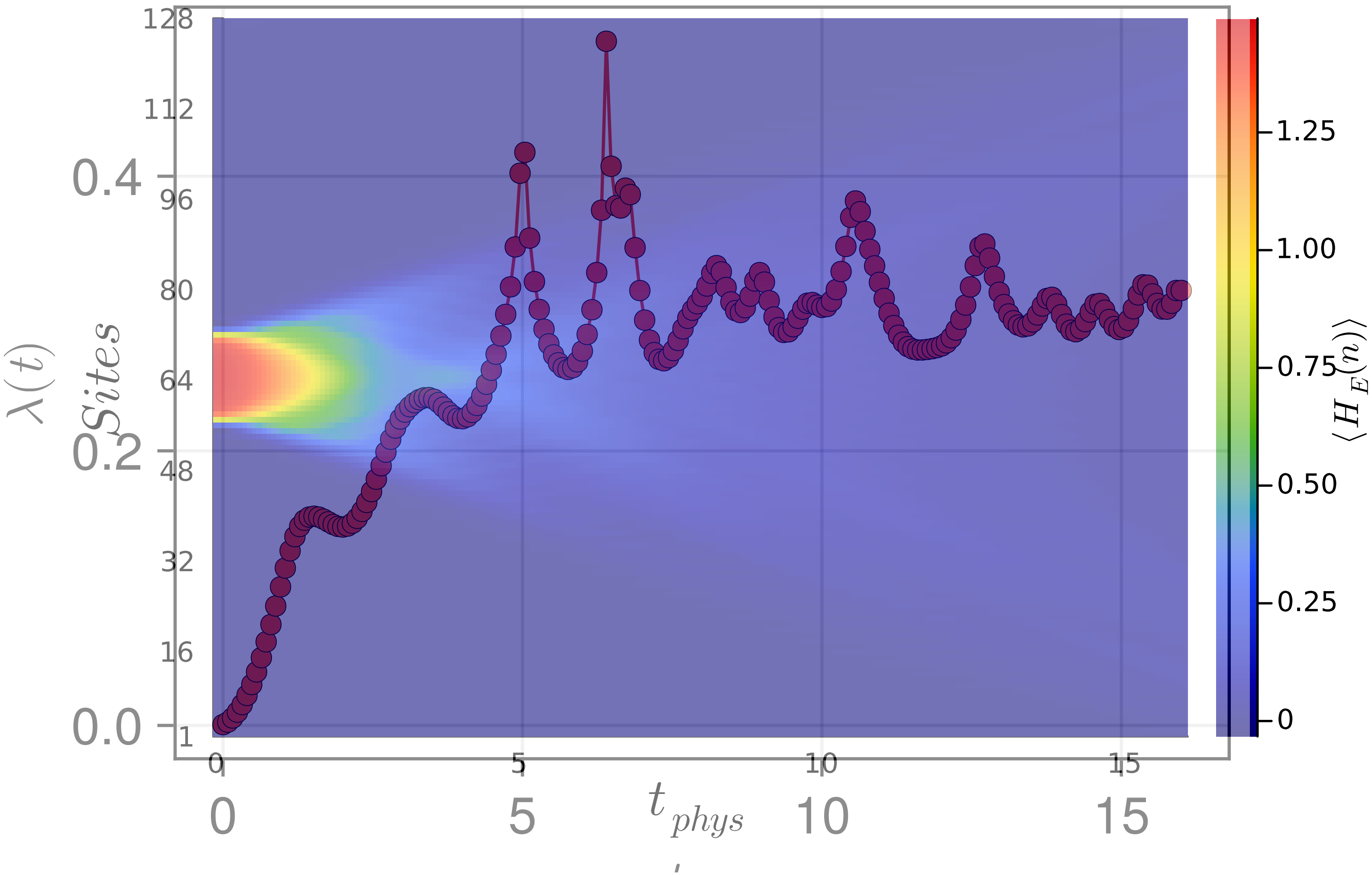
Time-evolution of a string state on the interacting vacuum





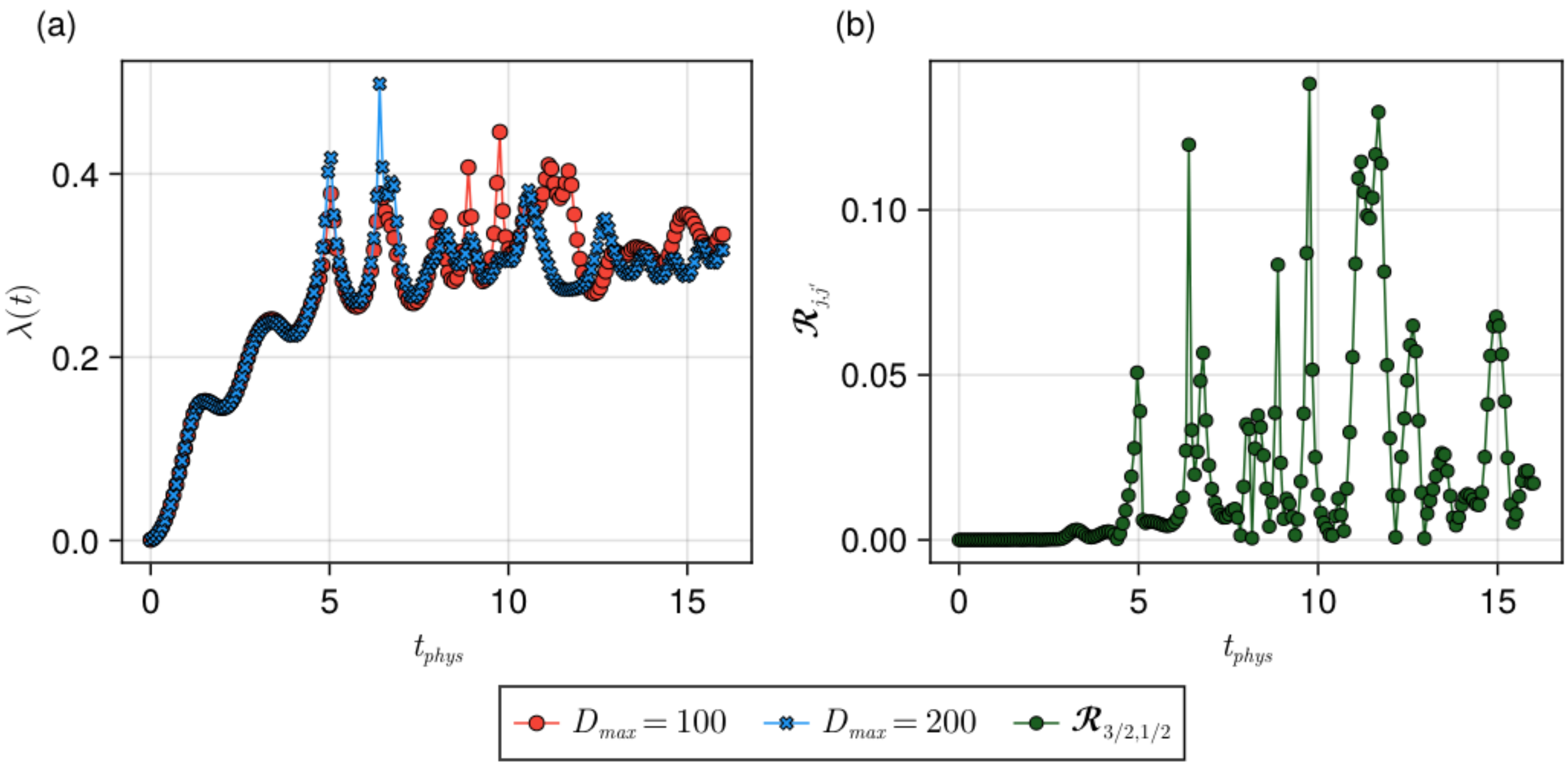
MPS Calculations using LSH framework

Time-evolution of a string state on the interacting vacuum



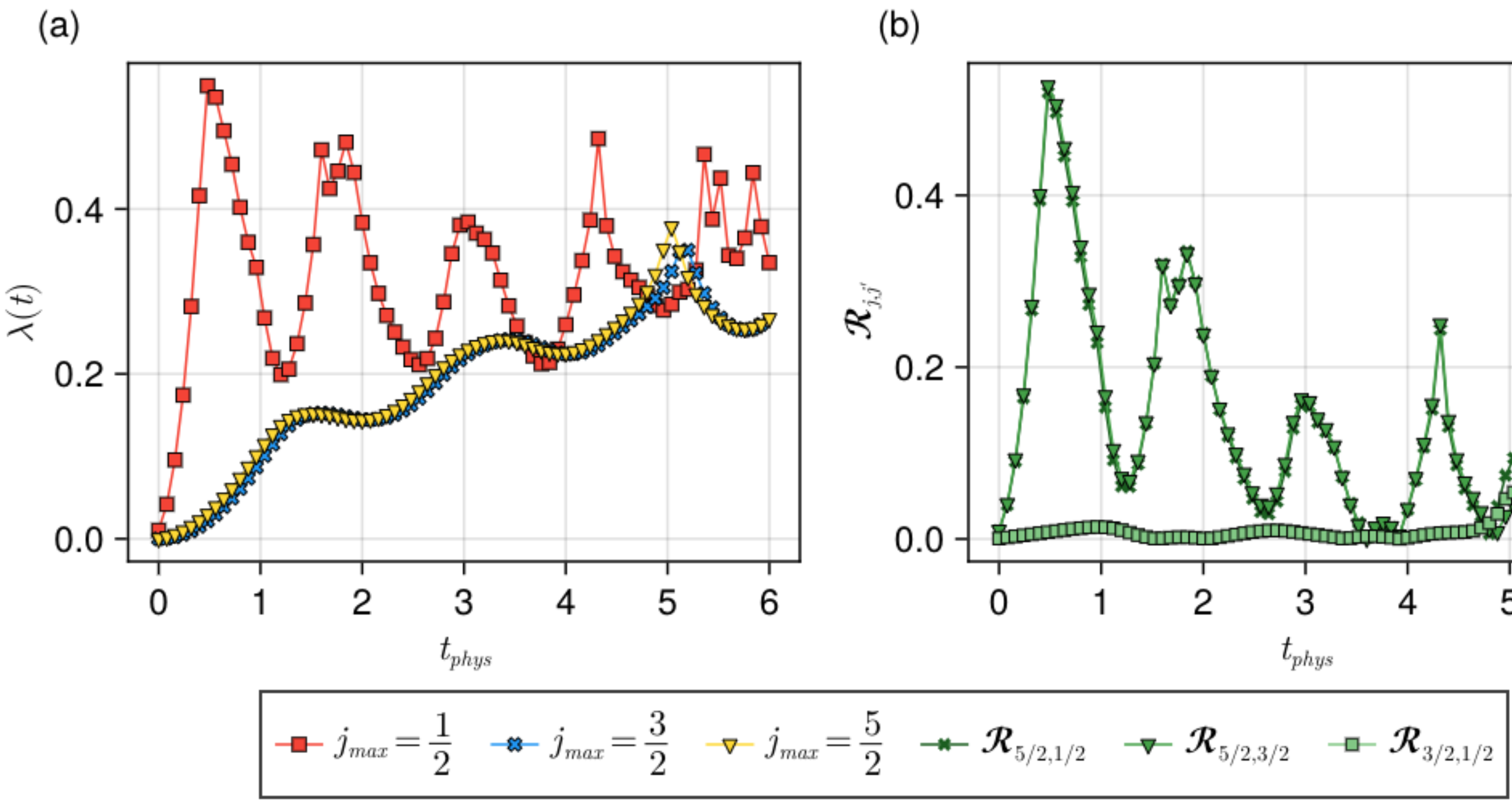
MPS Calculations using LSH framework

Probing effect of finite bond dimension: N=128



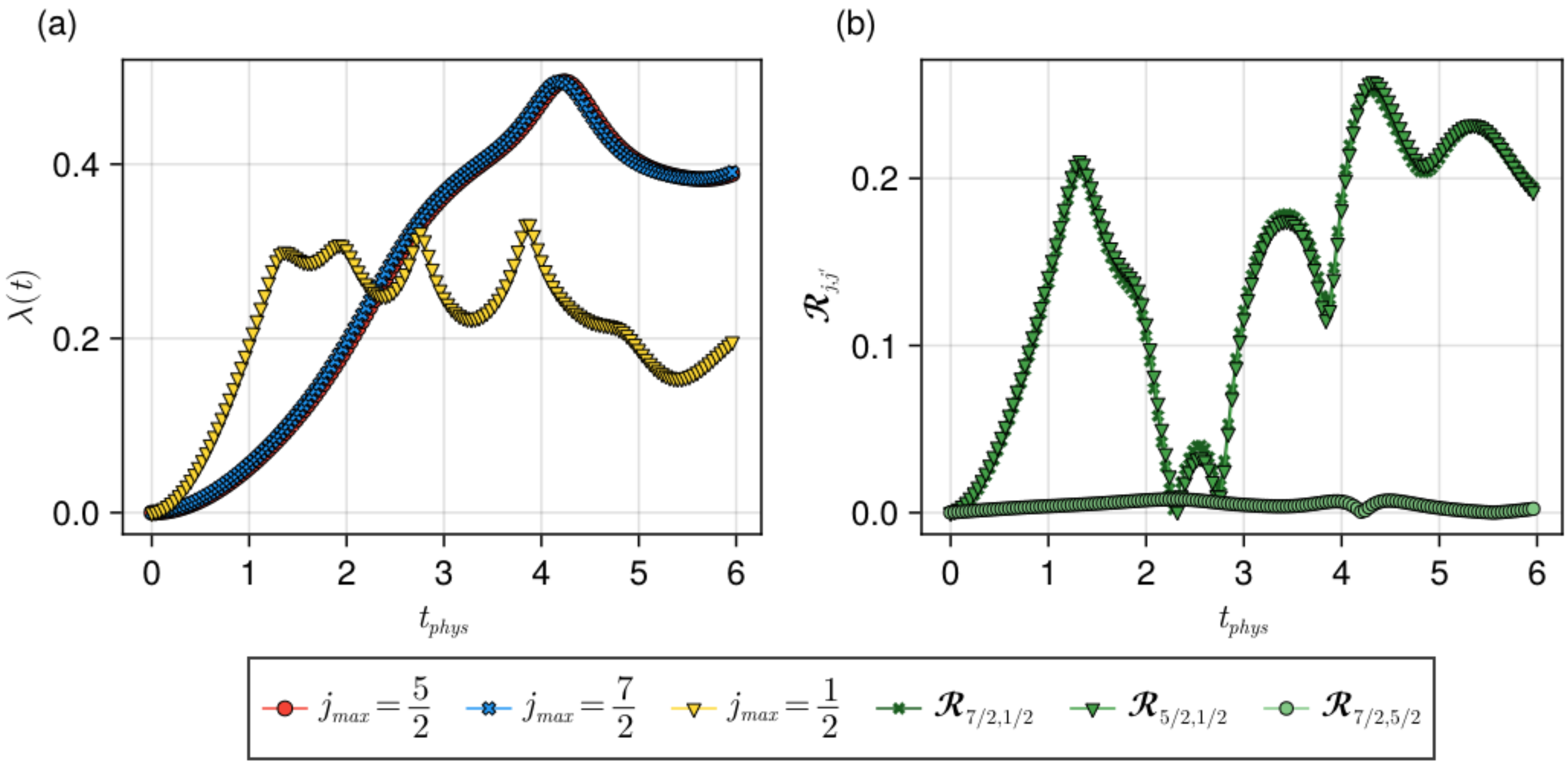
MPS Calculations using LSH framework

Probing cut-off dependence in dynamics: N=128



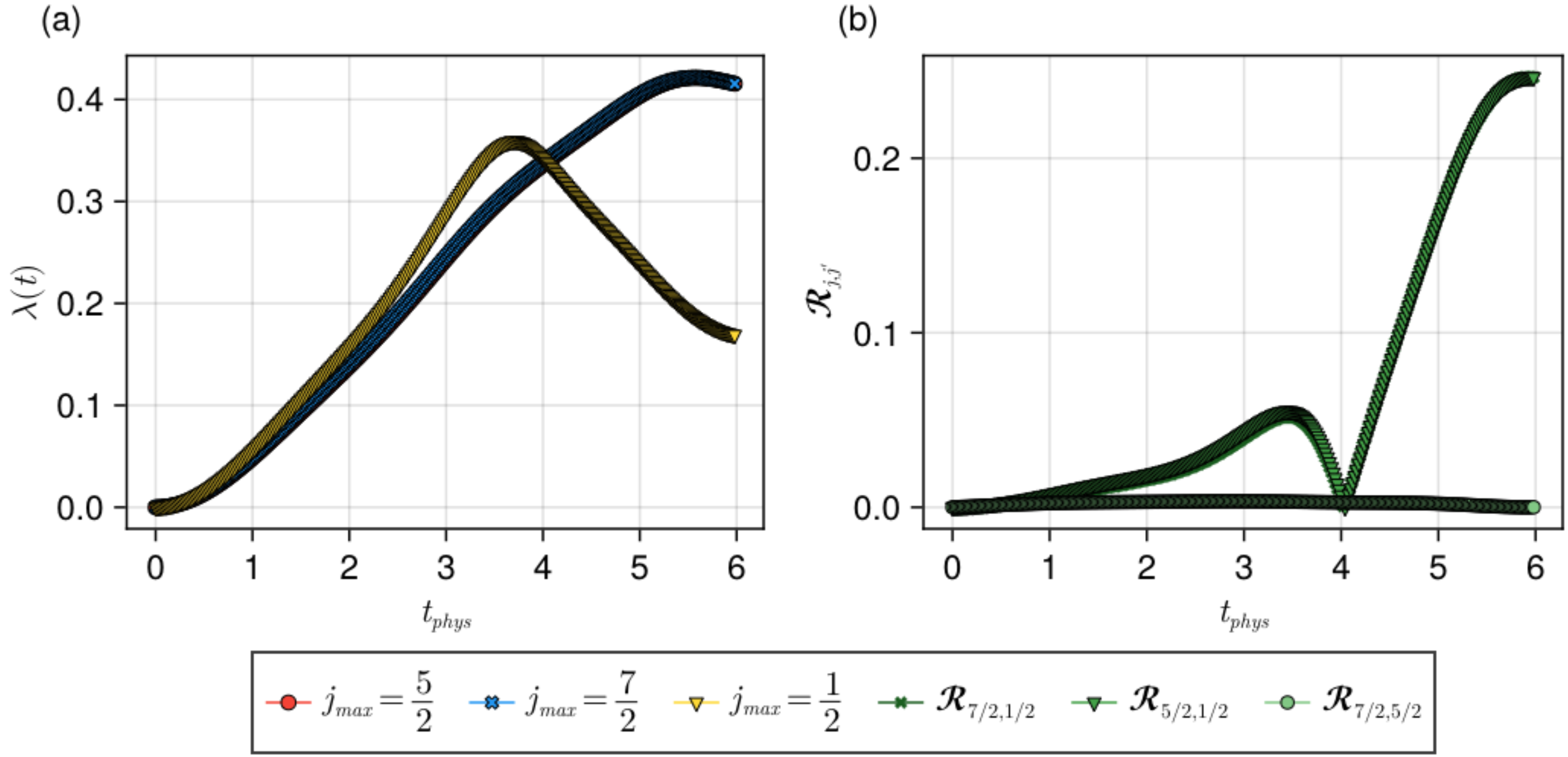
MPS Calculations using LSH framework

Probing cut-off dependence in dynamics: N=64



MPS Calculations using LSH framework

Probing cut-off dependence in dynamics: N=32



MPS Calculations using LSH framework

Probing the continuum limit of dynamics

....in progress
(both in static and dynamical observables)

Tensor Network Approach to LSH

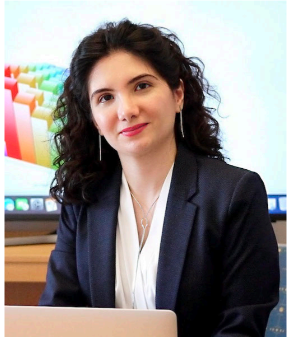
Collaborators:


Emil Mathew


Navya Gupta


Aniruddha Bapat


Saurabh Kadam


Zohreh Davoudi


Jesse Stryker

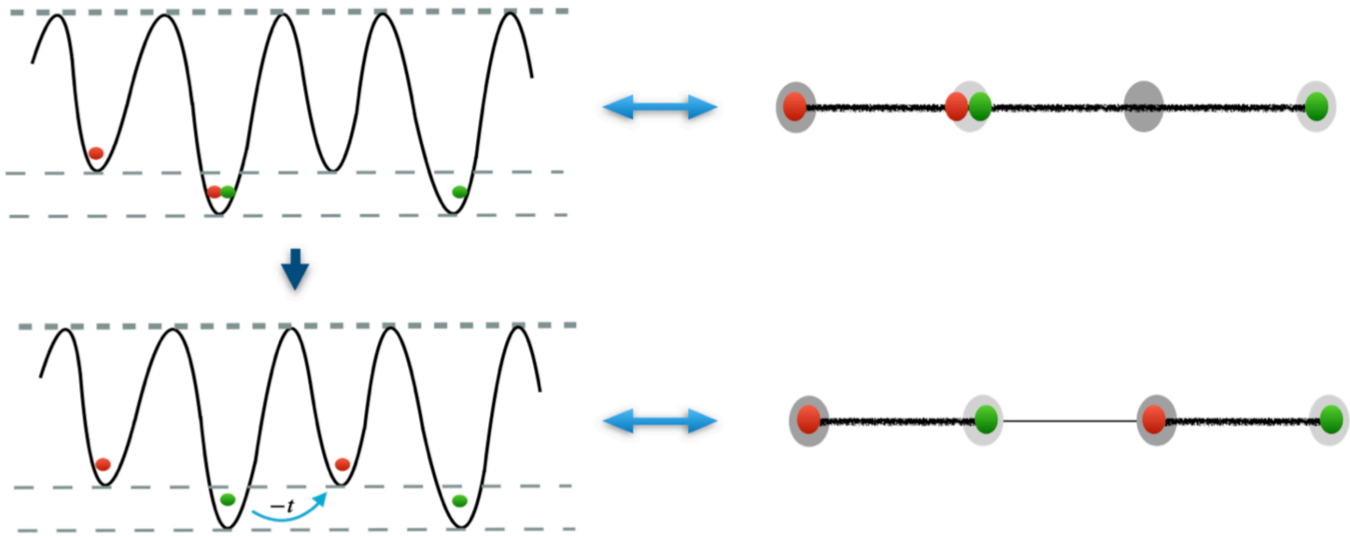

Nikko Pomata

Analog Quantum Simulation

PHYSICAL REVIEW A **105**, 023322 (2022)

Cold-atom quantum simulator for string and hadron dynamics in non-Abelian lattice gauge theory

Raka Dasgupta [1,*] and Indrakshi Raychowdhury [2,3,†]



Digital Quantum Computation

PHYSICAL REVIEW RESEARCH **2**, 033039 (2020)

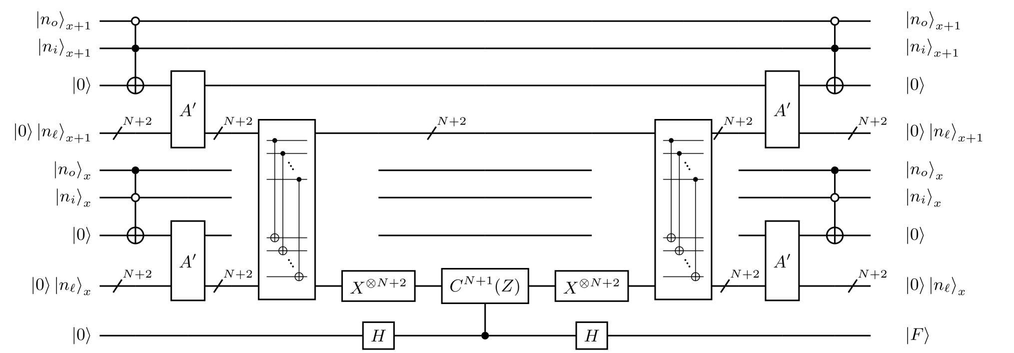
Solving Gauss's law on digital quantum computers with loop-string-hadron digitization

Indrakshi Raychowdhury*
Maryland Center for Fundamental Physics and Department of Physics, University of Maryland, College Park, Maryland 20742, USA

Jesse R. Stryker†
Institute for Nuclear Theory, University of Washington, Seattle, Washington 98195, USA

General quantum algorithms for Hamiltonian simulation with applications to a non-Abelian lattice gauge theory

Zohreh Davoudi,[1,2,*] Alexander F. Shaw,[3,†] and Jesse R. Stryker[1,‡]



"The loop-string-hadron formulation further retains the non-Abelian gauge symmetry despite the inexactness of the digitized simulation, without the need for costly controlled operations. Such theoretical and algorithmic considerations are likely to be essential in quantumly simulating other complex theories of relevance to nature."

A detailed analysis establishes benefits of using LSH framework on universal quantum computers both in

near-term

m/g	$\Delta_{\text{Trot.}}$	x	L	η	t/a_s	Schwinger bosons Qubits	Schwinger bosons Min. s	Schwinger bosons Min. CNOTs	LSH Qubits	LSH Min. s	LSH Min. CNOTs
1	10%	0.1	10	2	1	92	186	4.8613×10^6	40	63	2.63088×10^5
1	10%	0.1	10	2	5	92	2072	5.41538×10^7	40	702	2.93155×10^6
1	10%	0.1	10	4	1	164	433	5.21403×10^8	60	136	1.64261×10^6
1	10%	0.1	10	4	5	164	4841	5.82936×10^9	60	1519	1.83465×10^7
1	10%	0.1	20	2	1	192	262	1.44561×10^7	80	89	7.84624×10^5
1	10%	0.1	20	2	5	192	2929	1.61611×10^8	80	993	8.75429×10^6
1	10%	0.1	20	4	1	344	613	1.55832×10^9	120	193	4.92111×10^6
1	10%	0.1	20	4	5	344	6846	1.74034×10^{10}	120	2149	5.47952×10^7

far-term

m/g	x	η	L	t/a_s	Δ	$\alpha_{\text{Trot.}}$	$\alpha_{\text{Newt.}}$	Schwinger bosons Qubits	Schwinger bosons T gates	LSH Qubits	LSH T gates
1	1	4	100	1	0.01	90%	9%	2626	8.19713×10^{11}	1319	3.91817×10^{10}
1	1	4	100	1	0.001	90%	9%	2704	3.09951×10^{12}	1397	1.5172×10^{11}
1	1	4	100	10	0.01	90%	9%	2704	3.0993×10^{13}	1397	1.51643×10^{12}
1	1	4	100	10	0.001	90%	9%	2808	1.2146×10^{14}	1475	5.76229×10^{12}
1	1	4	1000	1	0.01	90%	9%	18904	3.12769×10^{13}	6797	1.53099×10^{12}
1	1	4	1000	1	0.001	90%	9%	19008	1.22564×10^{14}	6875	5.81562×10^{12}
1	1	4	1000	10	0.01	90%	9%	19008	1.22564×10^{15}	6875	5.81468×10^{13}
1	1	4	1000	10	0.001	90%	9%	19086	4.48657×10^{15}	6979	2.29217×10^{14}

Way to a complete SU(3) LSH framework

PHYSICAL REVIEW D **107,** 094513 (2023)

Loop-string-hadron formulation of an SU(3) gauge theory with dynamical quarks

Saurabh V. Kadam,[1,*] Indrakshi Raychowdhury,[2,†] and Jesse R. Stryker[1,‡]

[1] *Maryland Center for Fundamental Physics, University of Maryland, College Park, Maryland 20742, USA*

[2] *Department of Physics, BITS-Pilani, K K Birla Goa Campus, Zuarinagar, Goa 403726, India*

Jesse Stryker

Saurabh Kadam

Way to a complete SU(3) LSH framework

- Sneak-peak into the underlying pre potential framework: SU(2) vs SU(3)

e.g. in 1 spatial dimension

SU(2):

n $\qquad$ $n+1$

$a^\dagger_\alpha(n-1,R)$ $\quad$ $a^\dagger_\alpha(n,L)$ $\quad$ $a^\dagger_\alpha(n,R)$ $\quad$ $a^\dagger_\alpha(n+1,L)$

Irrep by Schwinger boson construction: monomial

$$|j, m_L, m_R\rangle \equiv a_1^\dagger(n,L)^{j+m_L} a_2^\dagger(n,L)^{j-m_L} a_1^\dagger(n,R)^{j+m_R} a_2^\dagger(n,R)^{j-m_R} |0,0,0,0\rangle$$

SU(3):

n $\qquad$ $n+1$

$a^\dagger_\alpha(n-1,R)$ $\quad$ $a^\dagger_\alpha(n,L)$ $\quad$ $a^\dagger_\alpha(n,R)$ $\quad$ $a^\dagger_\alpha(n+1,L)$

$b^{\dagger\alpha}(n-1,R)$ $\quad$ $b^{\dagger\alpha}(n,L)$ $\quad$ $b^{\dagger\alpha}(n,R)$ $\quad$ $b^{\dagger\alpha}(n+1,L)$

Irrep by Schwinger boson construction: Not a monomial

An irrep must be traceless: $a \cdot b \approx 0$

Irreducible Schwinger Bosons for SU(3):

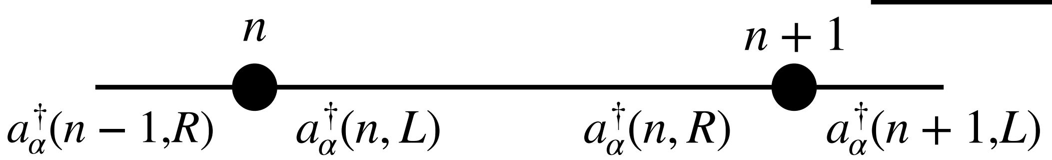
$$a^\dagger_\alpha, b^{\dagger\alpha} \rightarrow A^\dagger_\alpha, B^{\dagger\alpha}$$

Irrep by irreducible Schwinger boson construction: monomials

Way to a complete SU(3) LSH framework

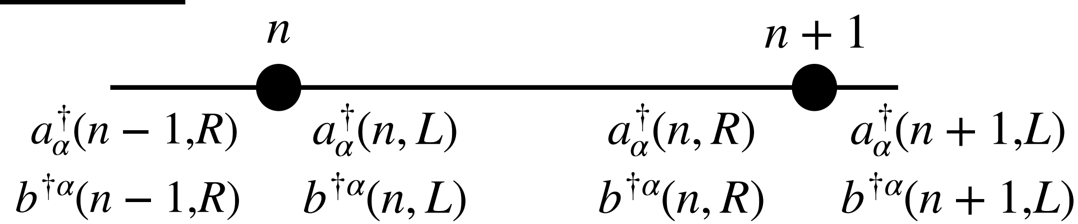
- Sneak-peak into the underlying pre potential framework: SU(2) vs SU(3)

e.g. in 1 spatial dimension



Irrep by Schwinger boson construction: monomial

$$|j,m_L,m_R\rangle \equiv a_1^\dagger(n,L)^{j+m_L} a_2^\dagger(n,L)^{j-m_L} a_1^\dagger(n,R)^{j+m_R} a_2^\dagger(n,R)^{j-m_R} |0,0,0,0\rangle$$



Irrep by Schwinger boson construction: Not a monomial

An irrep must be traceless: $a \cdot b \approx 0$

Irreducible Schwinger Bosons for SU(3):

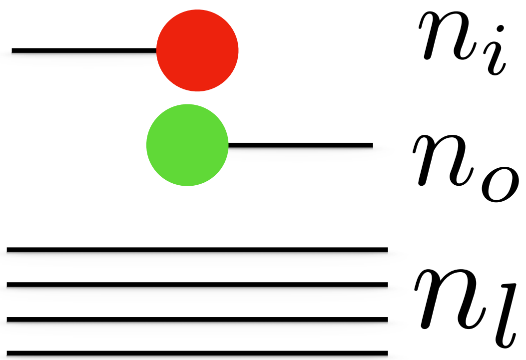
$$a^\dagger_\alpha, b^{\dagger\alpha} \rightarrow A^\dagger_\alpha, B^{\dagger\alpha}$$

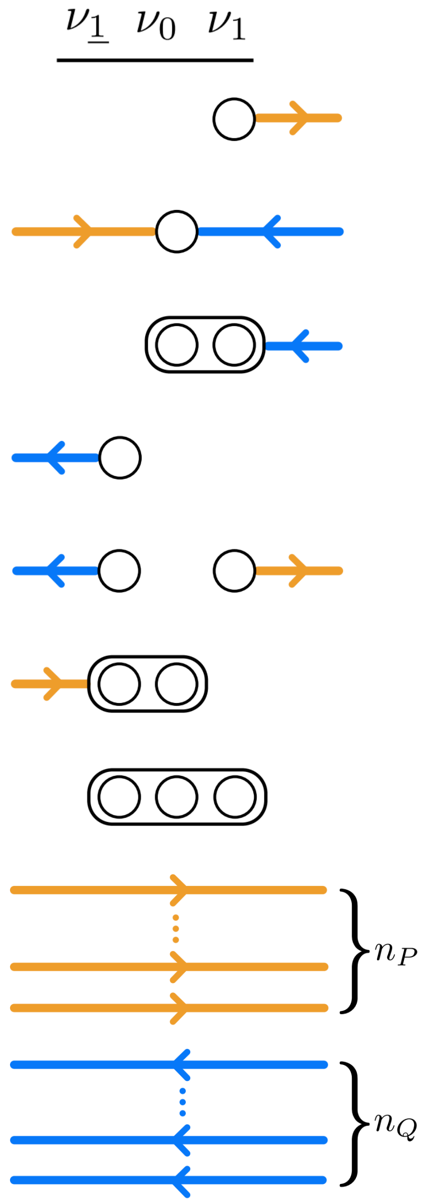
Irrep by irreducible Schwinger boson construction: monomials

Couple with fermions for both SU(2) and SU(3)

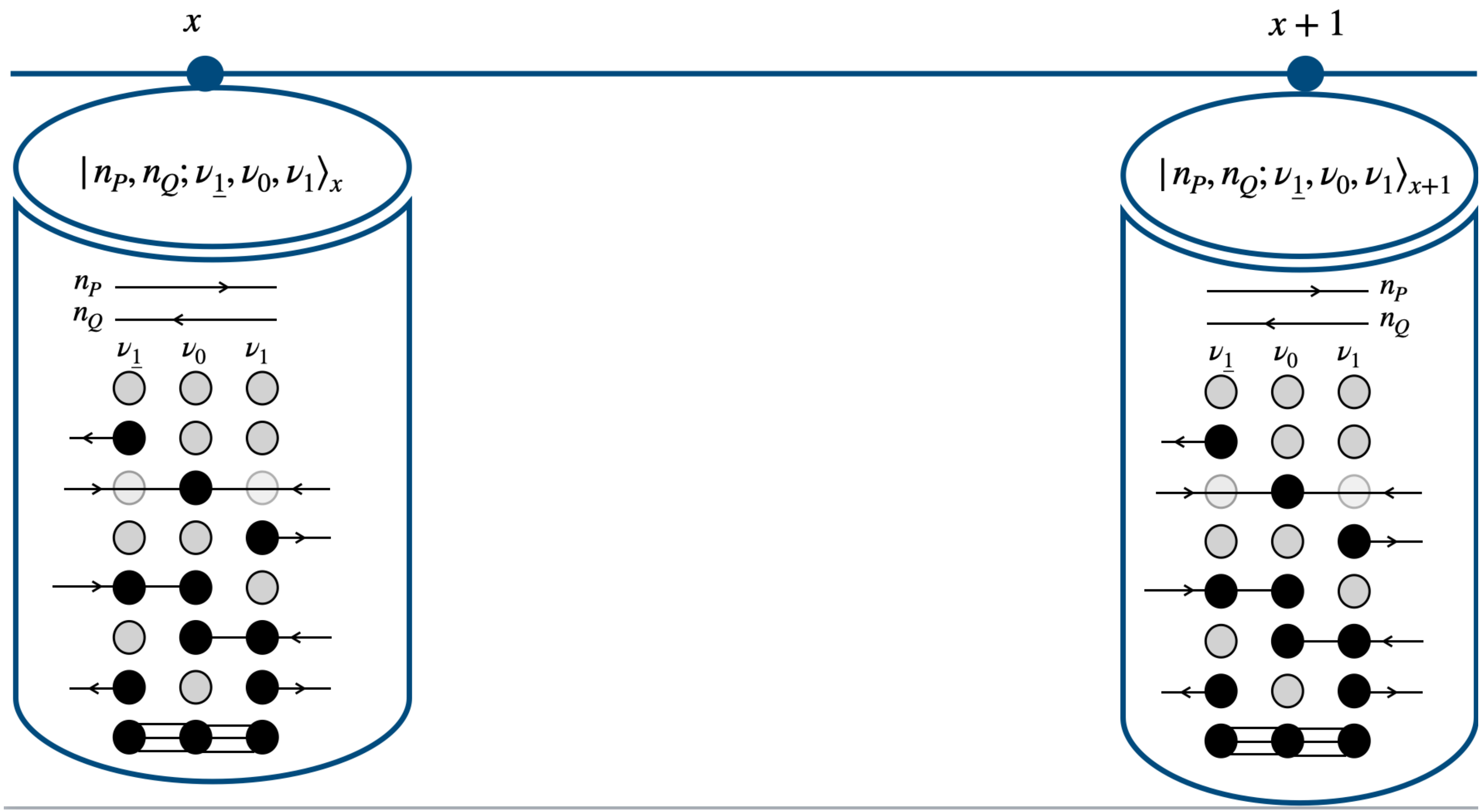
Local LSH states

SU(2) vs SU(3): 1d spatial lattice



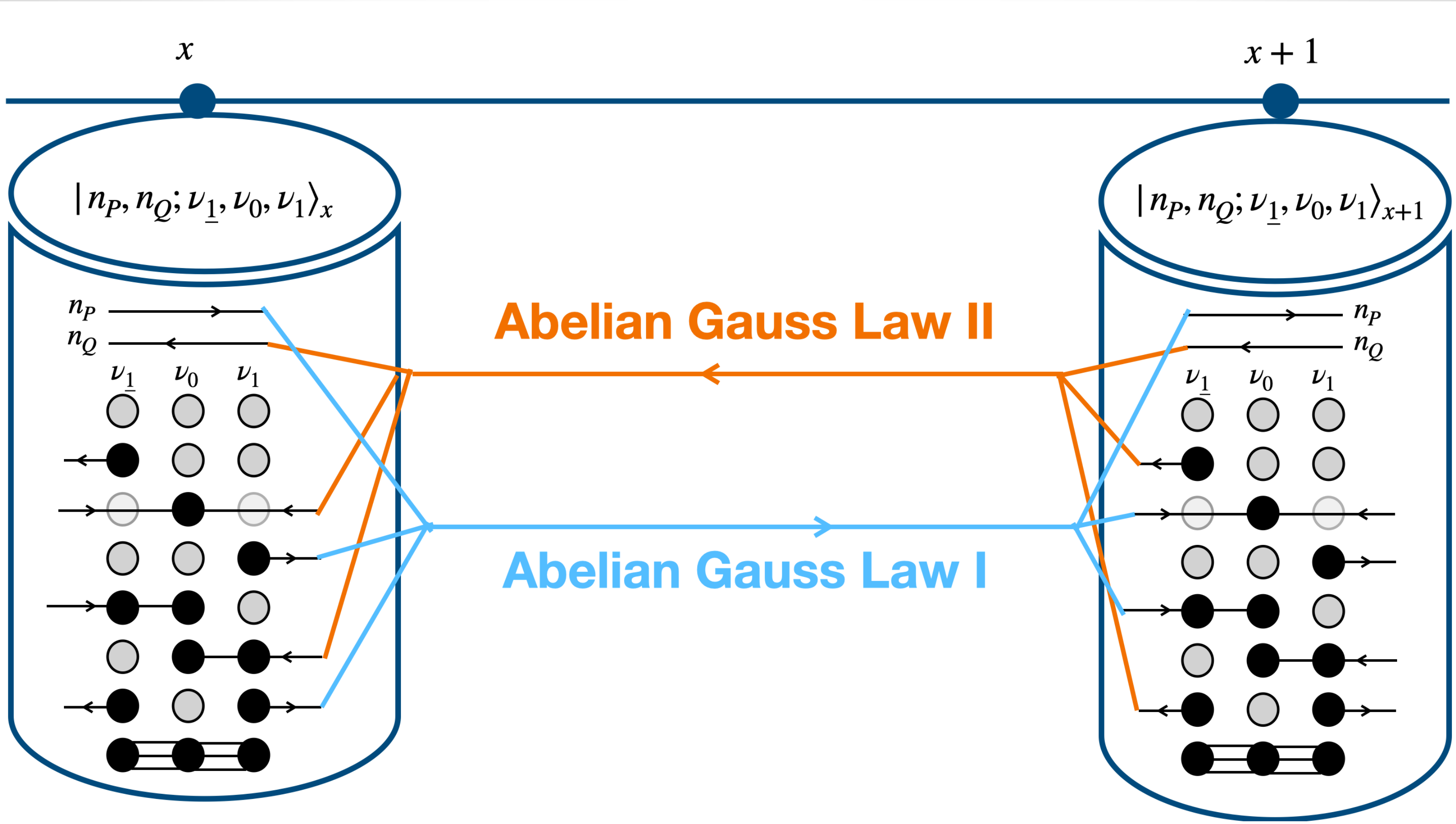


Loops-Strings-Hadrons : SU(3) in 1+1 d

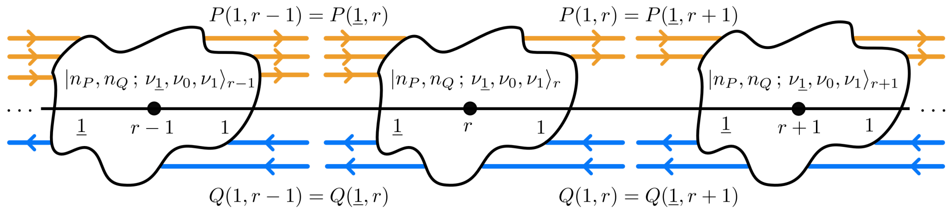


Loops-Strings-Hadrons : SU(2) in 1+1 d

Global LSH states are constructed by imposing a pair of Abelian Gauss Law constraints



LSH Formulation for SU(3): first step in 1+1 dimension is complete



Local LSH state:

$$\left|n_P,n_Q\,;\,\nu_{\underline{1}},\nu_0,\nu_1\right\rangle_r\,, \qquad n_P,n_Q\in\{0,1,2,\cdots\}, \qquad \nu_{\underline{1}},\nu_0,\nu_1\in\{0,1\},$$

Abelian Gauss laws

$$P(1,r)=P(\underline{1},r+1) \quad \text{and} \quad Q(1,r)=Q(\underline{1},r+1)$$

$$P(\underline{1},r)=n_P(r)+\nu_0(r)\,(1-\nu_1(r))$$
$$P(1,r)=n_P(r)+\nu_1(r)\,(1-\nu_0(r))$$

$$Q(\underline{1},r)=n_Q(r)+\nu_{\underline{1}}(r)\,(1-\nu_0(r))$$
$$Q(1,r)=n_Q(r)+\nu_0(r)\left(1-\nu_{\underline{1}}(r)\right)$$

Normalized ladder operators in LSH basis

$$\left|n_P, n_Q\,;\,\nu_{\underline{1}}, \nu_0, \nu_1\right\rangle_r$$

$$\left|n_P, n_Q\,;\,\nu_{\underline{1}}, \nu_0, \nu_1\right\rangle = (\hat{\Gamma}_P^\dagger)^{n_P} (\hat{\Gamma}_Q^\dagger)^{n_Q} (\hat{\chi}_{\underline{1}}^\dagger)^{\nu_{\underline{1}}} (\hat{\chi}_0^\dagger)^{\nu_0} (\hat{\chi}_1^\dagger)^{\nu_1} \left|0, 0\,;\,0, 0, 0\right\rangle$$

$$\hat{\Gamma}_P(r) = \sum_{n_P=1}^{\infty} \sum_{n_Q, \nu_{\underline{1}}, \nu_0, \nu_1} \left|n_P - 1, n_Q\,;\,\nu_{\underline{1}}, \nu_0, \nu_1\right\rangle \left\langle n_P, n_Q\,;\,\nu_{\underline{1}}, \nu_0, \nu_1\right|_r$$

$$\hat{\Gamma}_Q(r) = \sum_{n_Q=1}^{\infty} \sum_{n_P, \nu_{\underline{1}}, \nu_0, \nu_1} \left|n_P, n_Q - 1\,;\,\nu_{\underline{1}}, \nu_0, \nu_1\right\rangle \left\langle n_P, n_Q\,;\,\nu_{\underline{1}}, \nu_0, \nu_1\right|_r$$

$$\hat{\chi}_{\underline{1}}(r) = \sum_{n_P, n_Q, \nu_0, \nu_1} \left|n_P, n_Q\,;\,0, \nu_0, \nu_1\right\rangle \left\langle n_P, n_Q\,;\,1, \nu_0, \nu_1\right|_r$$

$$\hat{\chi}_0(r) = \sum_{n_P, n_Q, \nu_{\underline{1}}, \nu_1} \left|n_P, n_Q\,;\,\nu_{\underline{1}}, 0, \nu_1\right\rangle \left\langle n_P, n_Q\,;\,\nu_{\underline{1}}, 1, \nu_1\right|_r (-1)^{\nu_{\underline{1}}}$$

$$\hat{\chi}_1(r) = \sum_{n_P, n_Q, \nu_{\underline{1}}, \nu_0} \left|n_P, n_Q\,;\,\nu_{\underline{1}}, \nu_0, 0\right\rangle \left\langle n_P, n_Q\,;\,\nu_{\underline{1}}, \nu_0, 1\right|_r (-1)^{\nu_{\underline{1}} + \nu_0}$$

$$\begin{aligned}
\psi^\dagger \cdot B^\dagger(1),\ \psi^\dagger \cdot A(\underline{1}) &: \quad \text{apply } \hat{\chi}_1^\dagger, \\
\psi^\dagger \cdot B^\dagger(\underline{1}),\ \psi^\dagger \cdot A(1) &: \quad \text{apply } \hat{\chi}_{\underline{1}}^\dagger, \\
\psi^\dagger \cdot A^\dagger(1) \wedge B(1),\ \psi^\dagger \cdot A^\dagger(\underline{1}) \wedge B(\underline{1}),\ \psi^\dagger \cdot A^\dagger(\underline{1}) \wedge A^\dagger(1) &: \quad \text{apply } \hat{\chi}_0^\dagger, \\
A^\dagger(\underline{1}) \cdot B^\dagger(1) &: \quad \text{raise } \hat{n}_P \text{ by one,} \\
B^\dagger(\underline{1}) \cdot A^\dagger(1) &: \quad \text{raise } \hat{n}_Q \text{ by one.} \\
\psi^\dagger \cdot B^\dagger(\underline{1})\, \psi^\dagger \cdot B(1) &: \quad \text{apply } \hat{\chi}_{\underline{1}}^\dagger \chi_1^\dagger \\
\psi^\dagger \cdot \psi^\dagger \wedge A^\dagger(1) &: \quad \text{apply } \hat{\chi}_0^\dagger \chi_1^\dagger \\
\psi^\dagger \cdot \psi^\dagger \wedge A^\dagger(\underline{1}) &: \quad \text{apply } \hat{\chi}_{\underline{1}}^\dagger \chi_0^\dagger \\
\psi^\dagger \cdot \psi^\dagger \wedge \psi^\dagger &: \quad \text{apply } \hat{\chi}_{\underline{1}}^\dagger \hat{\chi}_0^\dagger \chi_1^\dagger
\end{aligned}$$

Irreducible Prepotentials to LSH

$$
\begin{aligned}
\psi^\dagger \cdot B^\dagger(1) &\mapsto \hat{\chi}^\dagger_1 (\hat{\Gamma}^\dagger_P)^{\hat{\nu}_0} \sqrt{\hat{n}_P + 2 - \hat{\nu}_0} \sqrt{\frac{\hat{n}_P + \hat{n}_Q + 3 + \hat{\nu}_0}{\hat{n}_P + \hat{n}_Q + 2 + \hat{\nu}_{\underline{1}} + \hat{\nu}_0}} \\
\psi \cdot B(1) &\mapsto \hat{\chi}_1 (\hat{\Gamma}_P)^{\hat{\nu}_0} \sqrt{\hat{n}_P + 2(1 - \hat{\nu}_0)} \sqrt{\frac{\hat{n}_P + \hat{n}_Q + 3}{\hat{n}_P + \hat{n}_Q + 2 + \hat{\nu}_{\underline{1}}}} \\
\psi^\dagger \cdot B^\dagger(\underline{1}) &\mapsto \hat{\chi}^\dagger_{\underline{1}} (\hat{\Gamma}^\dagger_Q)^{\hat{\nu}_0} \sqrt{\hat{n}_Q + 2 - \hat{\nu}_0} \sqrt{\frac{\hat{n}_P + \hat{n}_Q + 3 + \hat{\nu}_0}{\hat{n}_P + \hat{n}_Q + 2 + \hat{\nu}_1 + \hat{\nu}_0}} \\
\psi \cdot B(\underline{1}) &\mapsto \hat{\chi}_{\underline{1}} (\hat{\Gamma}_Q)^{\hat{\nu}_0} \sqrt{\hat{n}_Q + 2(1 - \hat{\nu}_0)} \sqrt{\frac{\hat{n}_P + \hat{n}_Q + 3}{\hat{n}_P + \hat{n}_Q + 2 + \hat{\nu}_1}} \\
\psi^\dagger \cdot A(1) &\mapsto \hat{\chi}^\dagger_{\underline{1}} (\hat{\Gamma}_Q)^{1-\hat{\nu}_0} \sqrt{\hat{n}_Q + 2\,\hat{\nu}_0} \sqrt{\frac{\hat{n}_P + \hat{n}_Q + 2 + \hat{\nu}_1}{\hat{n}_P + \hat{n}_Q + 2}} \\
\psi \cdot A^\dagger(1) &\mapsto \hat{\chi}_{\underline{1}} (\hat{\Gamma}^\dagger_Q)^{1-\hat{\nu}_0} \sqrt{\hat{n}_Q + 1 + \hat{\nu}_0} \sqrt{\frac{\hat{n}_P + \hat{n}_Q + 3 - \hat{\nu}_0 + \hat{\nu}_1}{\hat{n}_P + \hat{n}_Q + 3 - \hat{\nu}_0}} \\
\psi^\dagger \cdot A(\underline{1}) &\mapsto \hat{\chi}^\dagger_1 (\hat{\Gamma}_P)^{1-\hat{\nu}_0} \sqrt{\hat{n}_P + 2\,\hat{\nu}_0} \sqrt{\frac{\hat{n}_P + \hat{n}_Q + 2 + \hat{\nu}_{\underline{1}}}{\hat{n}_P + \hat{n}_Q + 2}} \\
\psi \cdot A^\dagger(\underline{1}) &\mapsto \hat{\chi}_1 (\hat{\Gamma}^\dagger_P)^{1-\hat{\nu}_0} \sqrt{\hat{n}_P + 1 + \hat{\nu}_0} \sqrt{\frac{\hat{n}_P + \hat{n}_Q + 3 - \hat{\nu}_0 + \hat{\nu}_{\underline{1}}}{\hat{n}_P + \hat{n}_Q + 3 - \hat{\nu}_0}} \\
\psi^\dagger \cdot A^\dagger(1) \wedge B(1) &\mapsto -\hat{\chi}^\dagger_0 (\hat{\Gamma}_P)^{1-\hat{\nu}_1} (\hat{\Gamma}^\dagger_Q)^{\hat{\nu}_{\underline{1}}} \sqrt{\hat{n}_P + 2\,\hat{\nu}_1} \sqrt{\hat{n}_Q + 2 - \hat{\nu}_{\underline{1}}} \\
\psi \cdot B^\dagger(1) \wedge A(1) &\mapsto \hat{\chi}_0 (\hat{\Gamma}^\dagger_P)^{1-\hat{\nu}_1} (\hat{\Gamma}_Q)^{\hat{\nu}_{\underline{1}}} \sqrt{\hat{n}_P + 1 + \hat{\nu}_1} \sqrt{\hat{n}_Q + 2(1 - \hat{\nu}_{\underline{1}})} \\
\psi^\dagger \cdot A^\dagger(\underline{1}) \wedge B(\underline{1}) &\mapsto \hat{\chi}^\dagger_0 (\hat{\Gamma}^\dagger_P)^{\hat{\nu}_1} (\hat{\Gamma}_Q)^{1-\hat{\nu}_{\underline{1}}} \sqrt{\hat{n}_P + 2 - \hat{\nu}_1} \sqrt{\hat{n}_Q + 2\,\hat{\nu}_{\underline{1}}} \\
\psi \cdot B^\dagger(\underline{1}) \wedge A(\underline{1}) &\mapsto -\hat{\chi}_0 (\hat{\Gamma}_P)^{\hat{\nu}_1} (\hat{\Gamma}^\dagger_Q)^{1-\hat{\nu}_{\underline{1}}} \sqrt{\hat{n}_P + 2(1 - \hat{\nu}_1)} \sqrt{\hat{n}_Q + 1 + \hat{\nu}_{\underline{1}}}
\end{aligned}
$$

$$
\begin{aligned}
\psi^\dagger \cdot B^\dagger(1),\ \psi^\dagger \cdot A(\underline{1}) &: \quad \text{apply } \hat{\chi}^\dagger_1, \\
\psi^\dagger \cdot B^\dagger(\underline{1}),\ \psi^\dagger \cdot A(1) &: \quad \text{apply } \hat{\chi}^\dagger_{\underline{1}}, \\
\psi^\dagger \cdot A^\dagger(1) \wedge B(1),\ \psi^\dagger \cdot A^\dagger(\underline{1}) \wedge B(\underline{1}),\ \psi^\dagger \cdot A^\dagger(\underline{1}) \wedge A^\dagger(1) &: \quad \text{apply } \hat{\chi}^\dagger_0, \\
A^\dagger(\underline{1}) \cdot B^\dagger(1) &: \quad \text{raise } \hat{n}_P \text{ by one,} \\
B^\dagger(\underline{1}) \cdot A^\dagger(1) &: \quad \text{raise } \hat{n}_Q \text{ by one.}
\end{aligned}
$$

$$
\begin{aligned}
\psi^\dagger \cdot B^\dagger(\underline{1})\, \psi^\dagger \cdot B(1) &: \quad \text{apply } \hat{\chi}^\dagger_{\underline{1}} \chi^\dagger_1 \\
\psi^\dagger \cdot \psi^\dagger \wedge A^\dagger(1) &: \quad \text{apply } \hat{\chi}^\dagger_0 \chi^\dagger_1 \\
\psi^\dagger \cdot \psi^\dagger \wedge A^\dagger(\underline{1}) &: \quad \text{apply } \hat{\chi}^\dagger_{\underline{1}} \chi^\dagger_0 \\
\psi^\dagger \cdot \psi^\dagger \wedge \psi^\dagger &: \quad \text{apply } \hat{\chi}^\dagger_{\underline{1}} \hat{\chi}^\dagger_0 \chi^\dagger_1
\end{aligned}
$$

Diagonal functions are in terms of

$$
\begin{aligned}
\hat{n}_l \left| n_P, n_Q; \nu_{\underline{1}}, \nu_0, \nu_1 \right\rangle &= n_l \left| n_P, n_Q; \nu_{\underline{1}}, \nu_0, \nu_1 \right\rangle, \\
\hat{\nu}_f \left| n_P, n_Q; \nu_{\underline{1}}, \nu_0, \nu_1 \right\rangle &= \nu_f \left| n_P, n_Q; \nu_{\underline{1}}, \nu_0, \nu_1 \right\rangle.
\end{aligned}
$$

$$l \in \{P, Q\}$$

$$f \in \{\underline{1}, 0, 1\}$$

LSH Hamiltonian for SU(3)

$$H = H_M + H_E + H_I$$

$$H_M = \sum_{r=1}^{N} H_M(r) \equiv \mu \sum_{r=1}^{N} (-1)^r \left(\hat{\nu}_{\underline{1}}(r) + \hat{\nu}_0(r) + \hat{\nu}_1(r)\right)$$

$$H_E = \sum_{r=1}^{N'} H_E(r) \equiv \sum_{r=1}^{N'} \frac{1}{3}\left(\hat{P}(1,r)^2 + \hat{Q}(1,r)^2 + \hat{P}(1,r)\hat{Q}(1,r)\right) + \hat{P}(1,r) + \hat{Q}(1,r)$$

$$\begin{aligned} H_I = \sum_{r=1}^{N'} H_I(r) \equiv \sum_r x &\left[\hat{\chi}_1^\dagger (\hat{\Gamma}_P^\dagger)^{\hat{\nu}_0} \sqrt{1 - \hat{\nu}_0/(\hat{n}_P + 2)} \sqrt{1 - \hat{\nu}_{\underline{1}}/(\hat{n}_P + \hat{n}_Q + 3)}\right]_r \otimes \left[\sqrt{1 + \hat{\nu}_0/(\hat{n}_P + 1)} \sqrt{1 + \hat{\nu}_{\underline{1}}/(\hat{n}_P + \hat{n}_Q + 2)}\, \hat{\chi}_1 (\hat{\Gamma}_P^\dagger)^{1-\hat{\nu}_0}\right]_{r+1} \\ + x &\left[\hat{\chi}_{\underline{1}}^\dagger (\hat{\Gamma}_Q)^{1-\hat{\nu}_0} \sqrt{1 + \hat{\nu}_0/(\hat{n}_Q + 1)} \sqrt{1 + \hat{\nu}_1/(\hat{n}_P + \hat{n}_Q + 2)}\right]_r \otimes \left[\sqrt{1 - \hat{\nu}_0/(\hat{n}_Q + 2)} \sqrt{1 - \hat{\nu}_1/(\hat{n}_P + \hat{n}_Q + 3)}\, \hat{\chi}_{\underline{1}} (\hat{\Gamma}_Q)^{\hat{\nu}_0}\right]_{r+1} \\ + x &\left[\hat{\chi}_0^\dagger (\hat{\Gamma}_P)^{1-\hat{\nu}_1} (\hat{\Gamma}_Q^\dagger)^{\hat{\nu}_{\underline{1}}} \sqrt{1 + \hat{\nu}_1/(\hat{n}_P + 1)} \sqrt{1 - \hat{\nu}_{\underline{1}}/(\hat{n}_Q + 2)}\right]_r \otimes \left[\sqrt{1 - \hat{\nu}_1/(\hat{n}_P + 2)} \sqrt{1 + \hat{\nu}_{\underline{1}}/(\hat{n}_Q + 1)}\, \hat{\chi}_0 (\hat{\Gamma}_P)^{\hat{\nu}_1} (\hat{\Gamma}_Q^\dagger)^{1-\hat{\nu}_{\underline{1}}}\right]_{r+1} \end{aligned}$$

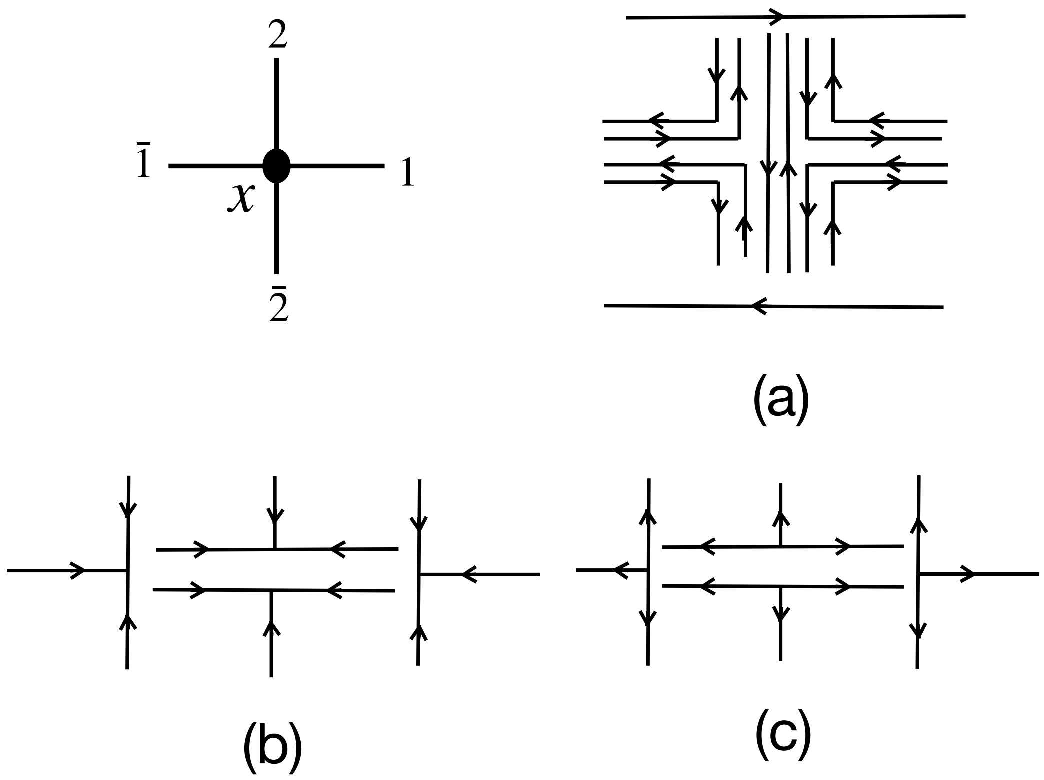
Numerically benchmarked with completely gauge fixed (pure gauge) Hamiltonian

Structurally identical to the SU(2) LSH construction

Loops-Strings-Hadrons : SU(3) beyond 1+1 d

Many surprises!

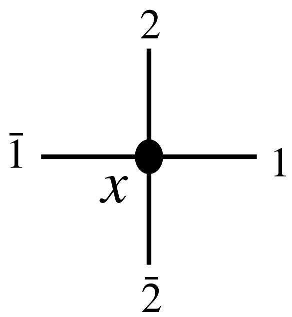
LSH Formulation for SU(3) in 2+1 dimension and beyond: generalising SU(2) construction

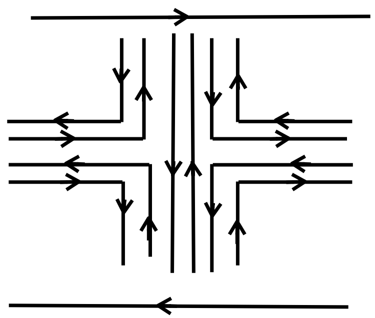


Loop configurations for 2d lattice

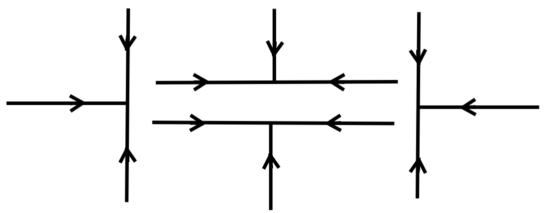
Too many redundant loop degrees of freedom

LSH Formulation for SU(3) in 2+1 dimension and beyond: generalising SU(2) construction

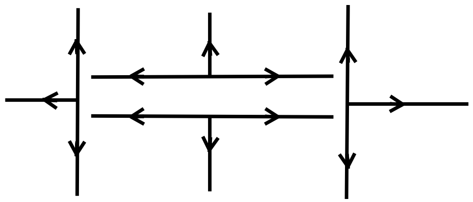




(a)



(b)

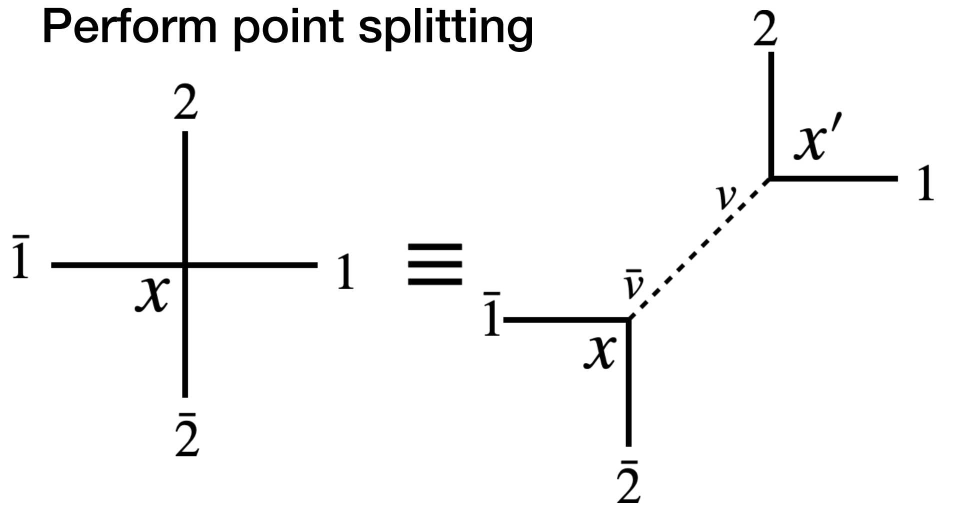


(c)

Loop configurations for 2d lattice

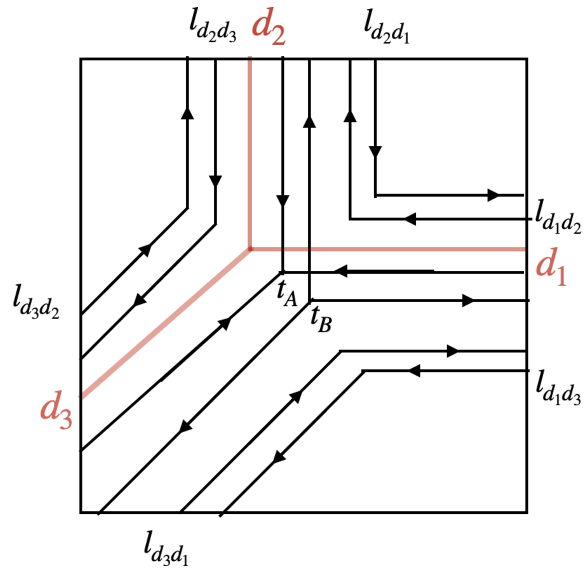
Too many redundant loop degrees of freedom

Perform point splitting

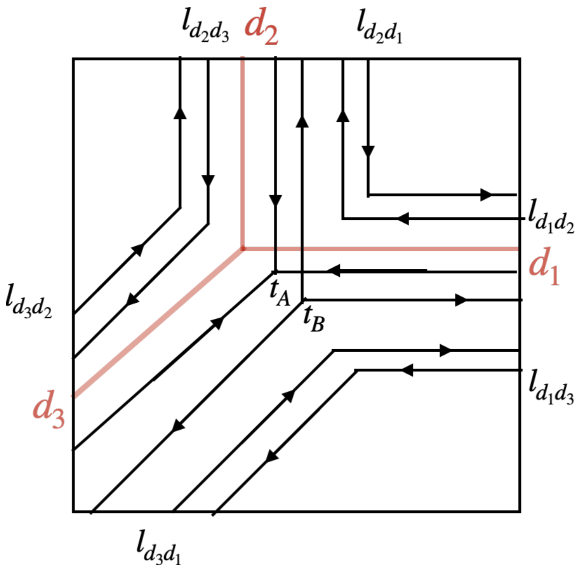


Loops on triangular lattice

Redundancy still persists



- Sneak-peak into the underlying SU(3) singlets



$$\begin{aligned}
\hat{L}_{IJ} &= \sum_{\alpha} A^{\dagger}_{\alpha}[I]B^{\dagger\alpha}[J] \ \text{for} I \neq J \\
\hat{T}^{A}_{IJK} &= \sum_{\alpha,\beta,\gamma} \epsilon^{\alpha\beta\gamma} A^{\dagger}_{\alpha}[I]A^{\dagger}_{\beta}[J]A^{\dagger}_{\gamma}[K] \\
\hat{T}^{B}_{IJK} &= \sum_{\alpha,\beta,\gamma} \epsilon_{\alpha\beta\gamma} B^{\dagger\alpha}[I]B^{\dagger\beta}[J]B^{\dagger\gamma}[K]
\end{aligned}$$

Mandelstam constraint: $\hat{T}^{A}\hat{T}^{B} = \hat{L}_{12}\hat{L}_{2v}\hat{L}_{v1} + \hat{\hat{L}}_{12}\hat{\hat{L}}_{2v}\hat{\hat{L}}_{v}$

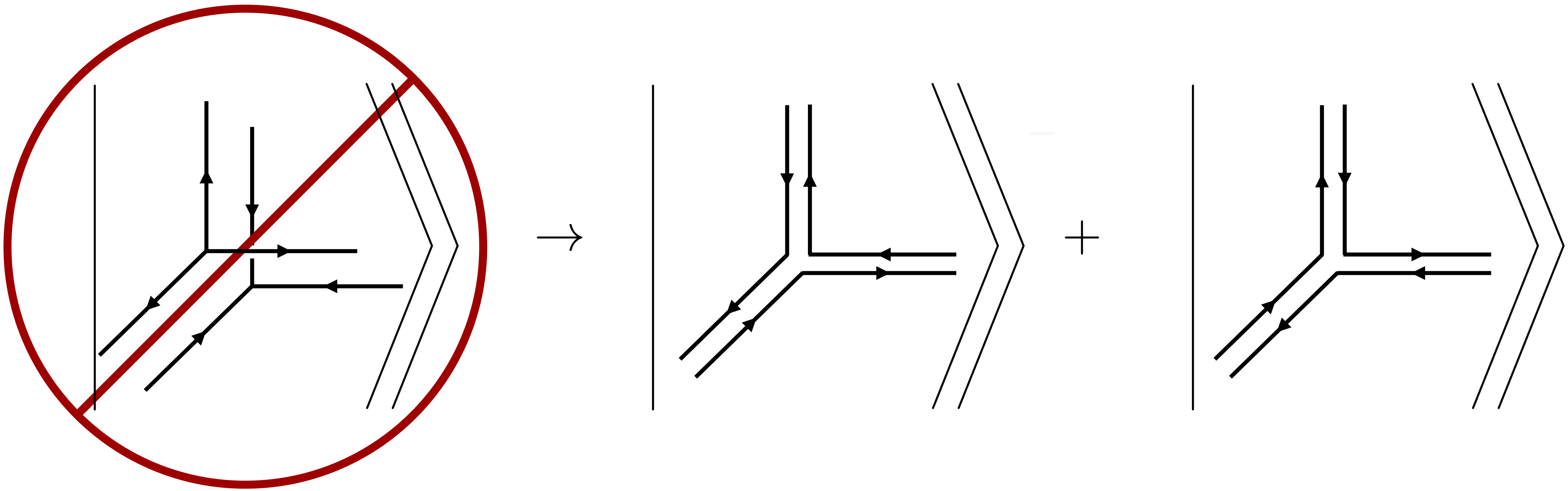
$$\begin{aligned}
&|l_{12}, l_{2v}, l_{v1}, l_{21}, l_{v2}, l_{1v}\,;\, t_A, t_B\rangle \\
= &\left(\hat{L}_{12}\right)^{l_{12}} \left(\hat{L}_{2v}\right)^{l_{2v}} \left(\hat{L}_{v1}\right)^{l_{v1}} \\
&\left(\hat{\hat{L}}_{12}\right)^{l_{21}} \left(\hat{\hat{L}}_{2v}\right)^{l_{v2}} \left(\hat{\hat{L}}_{v1}\right)^{l_{1v}} \\
&\left(\hat{T}^{A}\right)^{t_A} \left(\hat{T}^{B}\right)^{t_B} |0,0,0,0,0,0\,;\,0,0\rangle
\end{aligned}$$

Occupation number basis:
not a set of orthogonal quantum numbers

$$p_1 + p_2 + p_v = q_1 + q_2 + q_v + 3(t_A - t_B)$$

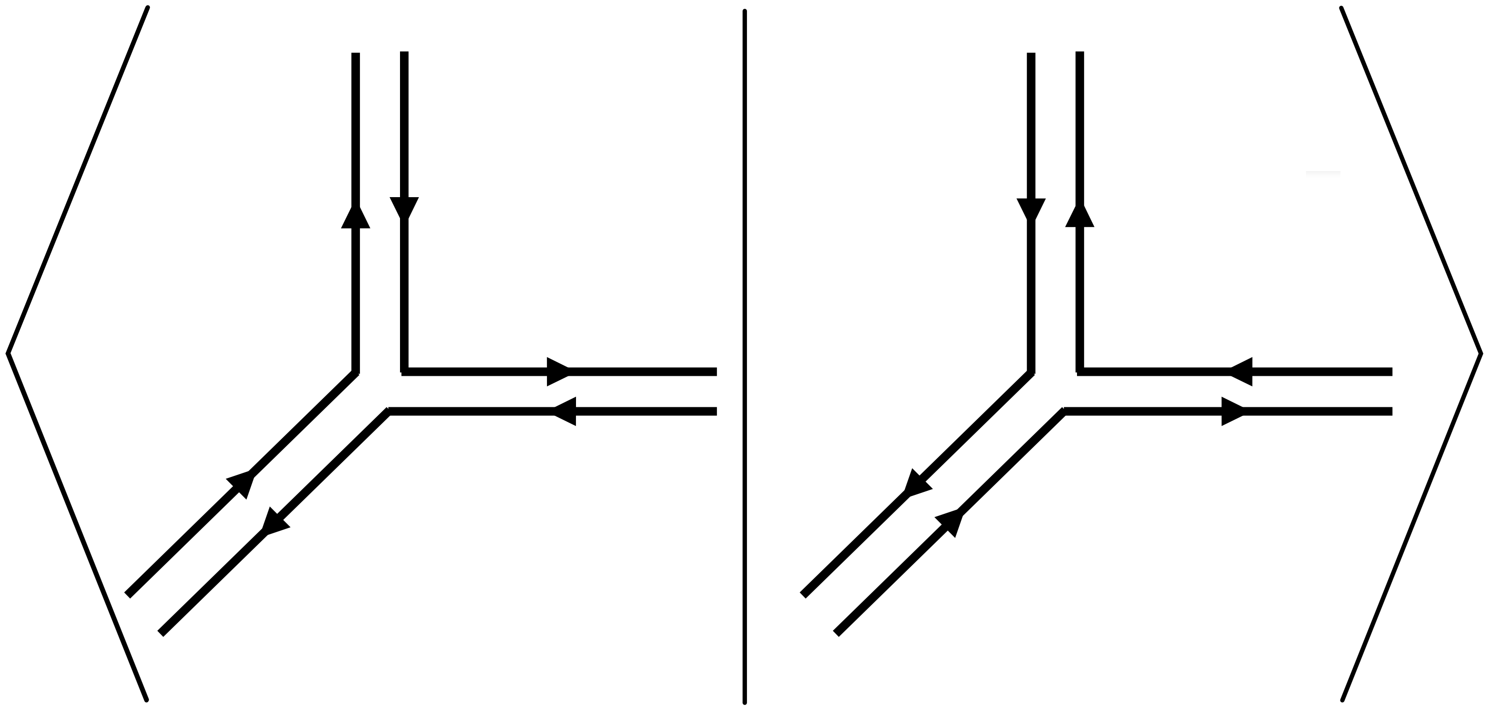
Search for a seventh Casimir quantum number begins…

Remnant Mandelstam Constraint



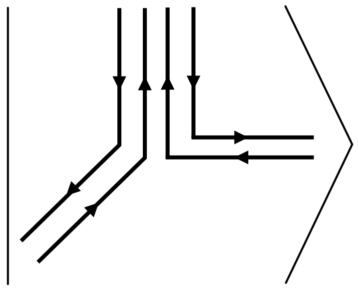
$$T_A^\dagger T_B^\dagger|0\rangle = |\ell_{12} = \ell_{23} = \ell_{31} = 1\rangle\rangle + |\ell_{21} = \ell_{32} = \ell_{13} = 1\rangle\rangle$$

Surprise: Non-orthogonality



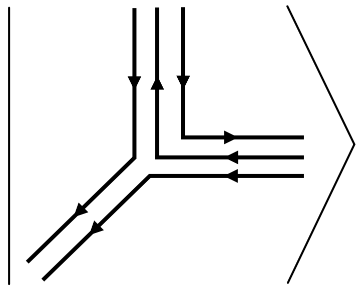
$$= -\frac{2}{7} \neq 0$$

Attempt to systematically study: orthogonal subspaces



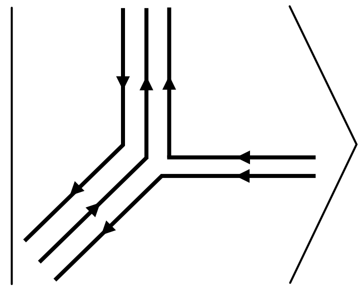
$= |\ell_{12} = \ell_{23} = \ell_{21} = \ell_{32} = 1\rangle$

Class I



$= |\ell_{12} = \ell_{23} = \ell_{21} = \ell_{13} = 1\rangle$

Class IIa



$= |\ell_{12} = \ell_{23} = \ell_{32} = \ell_{13} = 1\rangle$

Class IIb

Proposed Seventh Casimir to characterise the degenerate subspace

$$C_T \equiv (T_A T_B)^\dagger T_A T_B$$

arXiv:2407.19181v1 IQuS@UW-21-086

Loop-string-hadron approach to SU(3) lattice Yang-Mills theory: Gauge invariant Hilbert space of a trivalent vertex

Saurabh V. Kadam,[1,*] Aahiri Naskar,[2,†] Indrakshi Raychowdhury,[2,3,‡] and Jesse R. Stryker[4,5,§]

...in progress

Ongoing work in Hamiltonian construction;
Effort in making SU(3) LSH accessible for application.

Collaborators:

Aahiri Naskar,
Grad student,
BITS Goa

Jesse Stryker

Saurabh Kadam

...in progress

Thermalization

Thermalization of gauge theories

Sep 4, 2024, 3:30 PM
30m
B052 (ASC)

Speaker

Prof. Andreas Schäfer (University of Regensburg)

Description

Elucidating the microscopic mechanisms leading to thermalization of gauge theories is often advocated as an especially promising future application of quantum computing. What is usually not appreciated, however, is that many other approaches, e.g. lattice QCD, AdS/CFT duality, hydrodynamics, tensor networks, eigenstate thermalization (ETH) have already provided many complementary partial explanations and continue doing so. The talk will try to convey an impression of the existing web of methods and results, in which quantum computing still has to find its precise role. The talk will then focus on one very specific question, namely whether SU(2) gauge theory shows ETH properties. The answer, based on numerical simulations on classical, digital computers, turns out to be affirmative.

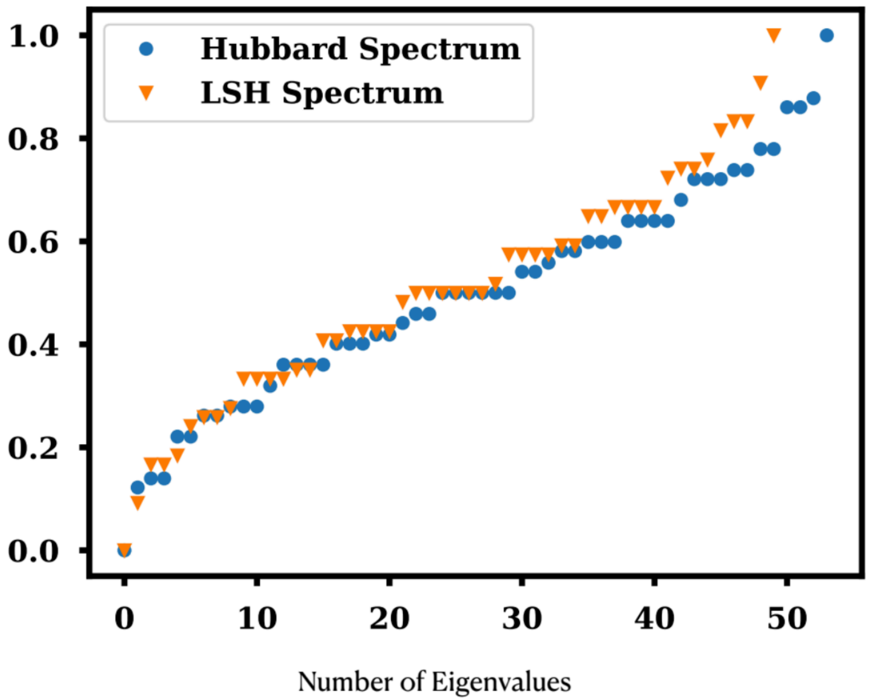
...in progress

Analog simulation

1+1d dynamics: dynamics of SU(3) strings and hadrons in LSH framework

Continuity of strings are guaranteed by AGL: protected by global symmetries

Simulated by SU(3) Fermi-Hubbard model



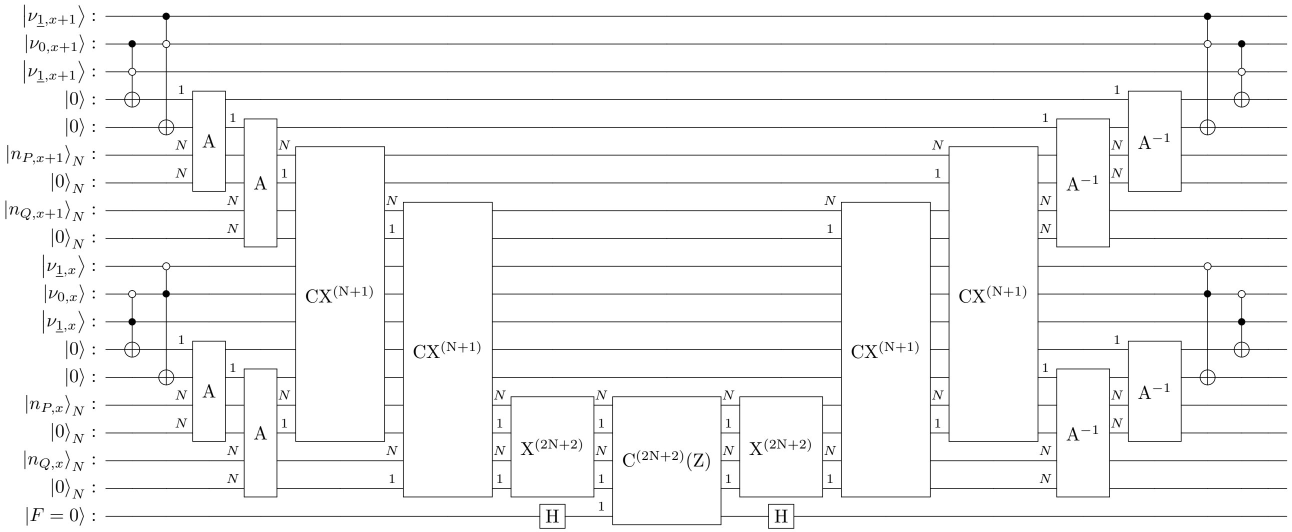
Collaborators: Madhumita Kabiraj, Emil Mathew, Raka Dasgupta

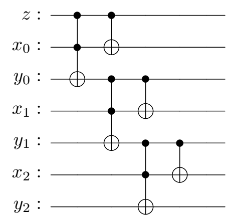
…in progress

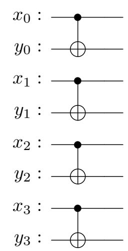
Digital Quantum Computing

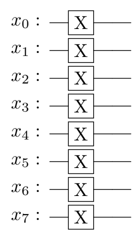
Fran Ilčić,
Grad. student,
BITS Goa

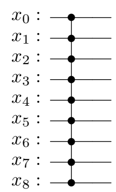
Physicality Oracle: Preliminary construction











Useful component for state preparation algorithms such as QAOA and error detection in a simulation

Summary and Outlook

Hamiltonian simulation of SU(2) gauge theory is a tough job

$\Rightarrow$ Considerably less progress in quantum simulating the same using angular momentum basis within KS framework

Summary and Outlook

Hamiltonian simulation of SU(2) gauge theory is a tough job

$\Rightarrow$ Considerably less progress in quantum simulating the same using angular momentum basis within KS framework

LSH framework of SU(2) LGT shows considerable advantage

$\Rightarrow$ Significant progress in the last couple of years in digital and analog quantum simulating the same

Summary and Outlook

Hamiltonian simulation of SU(2) gauge theory is a tough job

$\Rightarrow$ Considerably less progress in quantum simulating the same using angular momentum basis within KS framework

LSH framework of SU(2) LGT shows considerable advantage

$\Rightarrow$ Significant progress in the last couple of years in digital and analog quantum simulating the same

Hamiltonian simulation of SU(3) gauge theory is almost an impossible job

$\Rightarrow$ Anaogous SU(3) angular momentum basis is not well understood, No progress so far beyond fully gauge removed 1d lattice

Summary and Outlook

Hamiltonian simulation of SU(2) gauge theory is a tough job

$\Rightarrow$ Considerably less progress in quantum simulating the same using angular momentum basis within KS framework

LSH framework of SU(2) LGT shows considerable advantage

$\Rightarrow$ Significant progress in the last couple of years in digital and analog quantum simulating the same

Hamiltonian simulation of SU(3) gauge theory is almost an impossible job

$\Rightarrow$ Anaogous SU(3) angular momentum basis is not well understood, No progress so far beyond fully gauge removed 1d lattice

SU(3) LSH framework is in the making

$\Rightarrow$ Following the path of applications of SU(2) LSH, one can make the first concrete step towards quantum simulating QCD

Summary and Outlook

Hamiltonian simulation of SU(2) gauge theory is a tough job

⟹ Considerably less progress in quantum simulating the same using angular momentum basis within KS framework

LSH framework of SU(2) LGT shows considerable advantage

⟹ Significant progress in the last couple of years in digital and analog quantum simulating the same

Hamiltonian simulation of SU(3) gauge theory is almost an impossible job

⟹ Anaogous SU(3) angular momentum basis is not well understood, No progress so far beyond fully gauge removed 1d lattice

SU(3) LSH framework is in the making

⟹ Following the path of applications of SU(2) LSH,
The hope is to make the first concrete step towards quantum simulating QCD

LSH framework in 3+1 dimension including multiple quark flavours: QCD

Thank You

BITS Pilani
PILANI | DUBAI | GOA | HYDERABAD

SERB INDIA

CRQIT
Center for Research in Quantum Information and Technology

Collaborators:

University of Maryland 1856

BERKELEY LAB
Lawrence Berkeley National Laboratory

UNIVERSITY of WASHINGTON

Universität Regensburg

IQuS InQubator for Quantum Simulation

University of Calcutta – Advancement of Learning

Indian Institute of Technology Kanpur

Research group:

Emil Mathew
Grad student

Aahiri Naskar
Grad student

Fran Ilčić
Grad student