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III Brunel Workshop on Random Matrix Theory Fundamentals and Applications 17 December 2007

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Work in collaboration with Alexander Its and Man Yue Mo

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Consider a one-dimensional quantum spin chain:

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Consider a one-dimensional quantum spin chain:

Look at the ground state $j_{\ g}$ ih $_{\ g}j$

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Consider a one-dimensional quantum spin chain:

Look at the ground state $j_g ih_g j$ (T = 0: phase transition in the thermodynamic limit.)

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Consider a one-dimensional quantum spin chain:

Look at the ground state $j_g ih_g j$ (T = 0: phase transition in the thermodynamic limit.) Questions we can ask:

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Consider a one-dimensional quantum spin chain:

Look at the ground state $j_g ih_g j$ (T = 0: phase transition in the thermodynamic limit.) Questions we can ask:

What is the entropy of the entanglement between A and B as *L* ! 1 ? What is the correlation between two spins at di erent sites?

Many others.

If the model is:

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Jin and Korepin (2004):

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Jin and Korepin (2004): Spatial isotropy (= 0), next neighbour interaction and translation invariance (XX model, Toeplitz determinants).

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Its, Mezzadri and Mo (2007):

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The entropy of the entanglement can be written as $S(A) = \lim_{i=0^{+}} \lim_{L_{i}=1}^{i} \frac{1}{4i} e(1 + i) e(1 +$

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 $D_L($) is the determinant of the block-Toeplitz matrix

$$T_{L}[] = \begin{bmatrix} O & & & & 1 \\ B_{0} & B_{1} & B_{2} & L & B_{1} & L \\ B_{1} & B_{0} & & B_{3} & L & B_{2} & L \\ B_{1} & B_{0} & & B_{3} & L & B_{2} & L \\ B_{L 2} & B_{L 3} & & B_{0} & B_{1} & A \\ B_{L 1} & B_{L 2} & & B_{1} & B_{0} \end{bmatrix}$$

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 $g^2(z) = \int_{j=1}^{2^n} z^{j-1}$ Zj

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 $g^{2}(z) =$

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Remarks:

The branch cuts of g(z) are the segments

 $i = [2i \ i; 2i]; \quad i = 1; :::; 2n$

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g(z) has discontinuities $g_+(z) = g_-(z); z_- 2 = i$

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 $i = [2i \ i; 2i]; \quad i = 1; :::; 2n$

g(z) has discontinuities $g_+(z) = g_-(z); z_- 2_-i$ g(z) lives on the hyperelliptic curve

$$L: w^2 = \bigvee_{i=1}^{\forall n} (z \qquad i):$$

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 $i = [2i \ i; 2i]; \quad i = 1; :::; 2n$

g(z) has discontinuities $g_+(z) = g_-(z); z_- 2_-i$ g(z) lives on the hyperelliptic curve

$$L: w^2 = \bigvee_{i=1}^{\forall n} (z \qquad i):$$

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The genus of L is g = 2n - 1.

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Define : C^g ! C associated to L by $\binom{!s}{} := \frac{X}{\underset{n \ge Z^g}{}} e^{i \cdot \frac{!}{n} \cdot \frac{!}{n} \cdot \frac{!}{2} \cdot \frac{!}{2} \cdot \frac{!}{s} \cdot \frac{!}{n}}$

is a g g symmetric matrix (period matrix) that depends on the Hamiltonian through the branch cuts of L.

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What happens at a phase transition?

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How do we compute such formulae? The symbol $(z) = \int_{g^{-1}(z)}^{i} \frac{g(z)}{i}$ admits the Wiener-Hopf factorization:

 $(Z) = U_{+}(Z)U(Z) = V(Z)V_{+}(Z);$

where U(z) and V(z) are analytic inside/outside the unit circle and

U(1) = V(1) = I:

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Theorem (Widom, 1974)

 $\frac{d}{d} \log D_L() = \frac{2}{1-2}L$ $+\frac{1}{2} \int_{S^1}^{S^1} tr U_+^0$

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It turns out that

$$V(z) = {}_{3}U(z) {}^{1}{}_{3}$$

$$V_{+}(z) = {}_{3}U_{+}(z) {}^{1}{}_{3}({}^{2}{}_{-}1); \quad \Leftrightarrow \quad 1$$

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Let us de ne

$$S(z) = U(z)Q(z)^{-1};$$
 jzj 1;
 $S(z) = U_{+}(z)^{-1}Q(z);$ jzj 1:

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In order to compute the entropy of entanglement we need:

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In order to compute the entropy of entanglement we need:

1 to solve the previous RH problem for S(z) in terms of) $\beta 564$

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The critical case (phase transitions)

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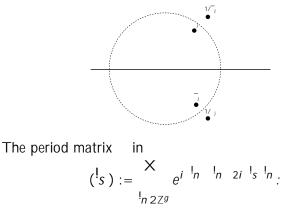
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The critical case (phase transitions)

Pairs of roots of g(z) approach the unit circle.



becomes degenerate.

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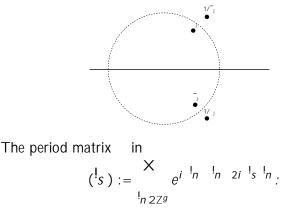
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The critical case (phase transitions)

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Pairs of roots of g(z) approach the unit circle.



becomes degenerate. ([!]s) becomes singular.

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We computed the entropy of the entanglement of the ground state of integrable quantum spin chains with nite range and translation invariant interaction.

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Summary

We computed the entropy of the entanglement of the ground state of integrable quantum spin chains with nite range and translation invariant interaction.

At the core of the computation is the evaluation of block-Toeplitz determinants.

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Summary

We computed the entropy of the entanglement of the ground state of integrable quantum spin chains with nite range and translation invariant interaction.

At the core of the computation is the evaluation of block-Toeplitz determinants.

Such determinants are computed by solving a RH problem. At phase transition we observe logarithmic divergences that generalize previous results.

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Summary

We computed the entropy of the entanglement of the ground state of integrable quantum spin chains with nite range and translation invariant interaction.

At the core of the computation is the evaluation of block-Toeplitz determinants.

Such determinants are computed by solving a RH problem. At phase transition we observe logarithmic divergences that generalize previous results.

AR Its, F Mezzadri and MY Mo. Entanglement entropy in quantum spin chains with nite range interaction. arXi v: 0708. 0161v1.