Average IPR vs Jz

- Description

  The Inverse Participation Ratio (IPR) of each eigenstate measures how much spread it is in a particular basis. A high value of IPR means that the eigenstate is spread out in that basis, while a low value of IPR means that the state is more localized. Here we choose the site-basis and compute the average value of the IPR's of all eigenstates for each value of Jz. (The code provided here is used to obtain the bottom of Figure 1 in the paper)

- Notation

  *) IPR = Inverse Participation Ratio

  *) AveIPR = average value of IPR for all eigenstates

- Code for IPR vs Jz

```
(*Parameters of the Hamiltonian*)
Clear[chainsize, upspins, downspins, dim, Jxy, Jz, open];
chainsize = 10;
upspins = chainsize / 2;
downspins = chainsize - upspins;
dim = chainsize! / (upspins! downspins!);
Jxy = 1.0;
Jz = 10;
open = 1;
(*Creating the basis*)
Clear[onebasisvector, basis];
onebasisvector =
  Flatten[{Table[1, {k, 1, upspins}], Table[0, {k, 1, downspins}]}];
basis = Permutations[onebasisvector];

total = 41;
(*Loop for values of Jz*)
Do[
  Jz = 0.5 (kk - 1);
  (*ELEMENTS OF THE HAMILTONIAN*)
  (*Initialization*)
  Clear[HH];
Do[Do[HH[i, j] = 0., {j, 1, dim}], {i, 1, dim}];

  (*Diagonal elements-Ising interaction*)
  Do[
   Do[
     HH[i, i] = HH[i, i] + (Jz / 4.) * (-1.)^(basis[[i, k]] + basis[[i, k + 1]]);
   , {k, 1, chainsize - 1}];
, {i, 1, dim}];
```

```
(*Term included in the Ising interaction if the chain is closed*)
If[open == 0,
   Do[HH[i, i] = HH[i, i] + (Jz / 4.) * (-1.)^(basis[[i, chainsize]] + basis[[i, 1]]),
    {i, 1, dim}]];

(*Off-diagonal elements-flip-flop term*)
  Clear[howmany, site];
Do[
   Do[
     (*Initialization*)
howmany = 0
Do[site[z] = 0, {z, 1, chainsize}];
(*Sites where states i and j differ*)
Do[If[basis[[i, k]] ≠ basis[[j, k]],
        {howmany = howmany + 1, site[howmany] = k}];, {k, 1, chainsize}];
(*Coupling matrix element-when only two neighbor sites differ*)
If[howmany == 2, If[site[2] - site[1] == 1,
       {HH[i, j] = HH[i, j] + Jxy / 2., HH[j, i] = HH[j, i] + Jxy / 2.}]];
(*Additional term for closed system*)If[open == 0, If[site[2] - site[1] ==
        chainsize - 1, {HH[i, j] = HH[i, j] + Jxy / 2., HH[j, i] = HH[j, i] + Jxy / 2.}]];
, {j, i + 1, dim}];
, {i, 1, dim - 1}];

  (* TOTAL HAMILTONIAN AND DIAGONALIZATION *)
  Clear[Hamiltonian, Energy, Vector];
  Hamiltonian = Table[Table[HH[i, j], {j, 1, dim}], {i, dim}];
  Energy = Eigenvalues[Hamiltonian];
  Vector = Eigenvectors[Hamiltonian];

  (*Inverse Participation Ratio:IPR*)

Clear[IPR];
IPR = 0.0;
Do[
   Clear[denom];
denom = Sum[Vector[[i, k]]^4, {k, 1, dim}];
IPR = IPR + 1 / denom;
, {i, 1, dim}];

  (*Average value of IPR*)
AveIPR[kk] = IPR / dim;
Print[{Jz, AveIPR[kk]}];
, {kk, 1, total}];

(*Plot:IPR vs Jz*)
Clear[tab];
tab = Table[{0.5 (kk - 1), AveIPR[kk]}, {kk, 1, total}];
```

```
ListPlot[tab, Joined → True, LabelStyle → Directive[Black, Bold, Medium],
 PlotStyle → {Blue, Thick}, AxesLabel → {"Jz", "<IPR>"}, PlotRange → All]
```

```
{0., 85.9309}
{0.5, 71.4578}
{1., 61.5901}
{1.5, 42.8816}
{2., 29.9447}
{2.5, 23.9343}
{3., 20.7038}
{3.5, 18.8467}
{4., 17.6992}
{4.5, 16.9437}
{5., 16.3867}
{5.5, 15.8928}
{6., 15.5}
{6.5, 15.272}
{7., 15.1101}
{7.5, 14.9732}
{8., 14.8432}
{8.5, 14.7534}
{9., 14.6785}
{9.5, 14.6154}
{10., 14.5618}
{10.5, 14.5154}
{11., 14.4739}
{11.5, 14.4308}
{12., 14.4083}
{12.5, 14.3641}
{13., 14.3418}
{13.5, 14.3119}
{14., 14.2947}
{14.5, 14.2693}
{15., 14.2523}
{15.5, 14.2087}
{16., 14.1804}
```

{16.5, 14.14}

{17., 14.0954}

{17.5, 14.0387}

{18., 13.9428}

{18.5, 13.7871}

{19., 13.7026}

{19.5, 13.5616}

{20., 13.4968}