capstract:2611.00057v1 [cond-mat.soft] 20 Nov 2026

Nematic ordering of mug handles in communal dish racks

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(Dated: November 20, 2026)

Mugs placed rim down on a dish rack have a definite orientation in plan view, set by the direction of the handle. We measured the handle angle of 20,251 mugs in 2,632 images of 94 communal racks, together with the writing hand of the 1,544 registered users. The handles lie along the long axis of the rack. Their nematic order projected on that axis rises with the mean number of contacts per mug, z, from 0.07 at $z < 0.5$ to 0.39 at $z = 3.6$, and is described by a Maier–Saupe mean-field model with a pair coupling $K = 0.47 \pm 0.04$ and a weak anchoring to the rack frame $w = 0.20 \pm 0.02$ ($\chi^2 = 3.3$ for 6 degrees of freedom). The model puts the isotropic–nematic transition at $z_c = 4.3 \pm 0.3$, beyond the largest contact number observed (3.87) and close to the isostatic value of 4 at which a rack can take no further mugs. Handles point to the right 2.2 times as often as to the left. The polar order of a rack falls with the fraction of left-handed users f_L as $P_x = P_0(1 - 2f_L)$ with $P_0 = 0.283 \pm 0.008$, which corresponds to a handedness field $b = 0.47 \pm 0.01$ in the units of the pair coupling.

PACS numbers: 61.30.-v, 45.70.-n, 05.70.Fh, 89.65.-s

I. INTRODUCTION

A mug is a cylinder with one handle. Placed rim down on a dish rack it has a definite orientation in plan view, set by the direction in which the handle points, and a collection of mugs on a rack is therefore a two-dimensional assembly of anisometric objects with a head and a tail. Assemblies of such objects are the subject of liquid-crystal physics [1], and the orientational states they can adopt are well catalogued: isotropic, nematic, and polar variants of both. We have not found a description of the state of a dish rack.

Rods confined to a plane order nematically above a critical density, by the excluded-volume mechanism of Onsager [2], and the two-dimensional case has been worked out for hard needles and for vibrated granular rods [3–5]. Mugs differ from rods in two ways. The handle makes them polar, so that the handle can point to the left or to the right of the rack. And the rack imposes both a boundary and a preferred axis, since the wires of a tray rack run parallel to its long side. The polar bias has an obvious external origin. A person puts a mug on the rack with the handle toward the hand that is free, and about one person in ten is left-handed [6]. Handedness therefore plays the role of a field that couples to the polar order parameter, with a sign that depends on who loaded the mug.

This note reports the orientation of 20,251 handles in 94 communal dish racks. We ask three questions. Do the handles order, and what controls the order? Is the preferred direction set by the handedness of the users? And at what density, if any, does the rack leave the isotropic state? The sections below give a mean-field description (Sec. II), the measurements (Sec. III) and the results (Sec. IV). Section V discusses why the last question has no direct answer.

II. MODEL

A. Orientational energy

Let ϕ_i be the angle of the handle of mug i in plan view, measured from the long axis of the rack, with $\phi = 0$ when the handle points to the right of a person facing the rack. A pair of mugs in contact interacts through the nematic coupling $-K\cos 2(\phi_i - \phi_j)$, which is symmetric under $\phi \to \phi + \pi$ because two handles that point toward or away from each other are equally compatible with the packing. The rack frame contributes an anchoring term $-w\cos 2\phi_i$ favouring alignment with the long axis. The loader contributes $-b\,s_i\cos\phi_i$, with $s_i = +1$ for a right-handed loader and -1 for a left-handed one. The energy is

$$\frac{H}{\tau} = -K\sum_{\langle ij\rangle}\cos 2(\phi_i - \phi_j) - w\sum_i \cos 2\phi_i - b\sum_i s_i\cos\phi_i, \tag{1}$$

where the sum over $\langle ij\rangle$ runs over pairs of mugs whose centres lie within $1.5\,D$ of each other, D is the mug diameter, and τ is the scale of the loader's placement noise, which sets the unit of K, w and b. A mug is not equilibrated by a thermal bath, so Eq. (1) is an effective description that we test, not a derivation. The observables are the projection of the nematic order on

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the rack axis, $S_x = \langle \cos 2\phi \rangle$, and the polar order $P_x = \langle \cos \phi \rangle$.

B. Mean field

Let z be the mean number of contacts per mug. Replacing the neighbours of a mug by their mean orientation gives a single-site weight $\exp(m \cos 2\phi)$ with $m = K z S_x + w$, and

$$S_x = \frac{I_1(m)}{I_0(m)}, \qquad m = K z\, S_x + w, \tag{2}$$

where I_n are modified Bessel functions. For small m, $I_1/I_0 \simeq m/2$. With $w = 0$ the isotropic solution $S_x = 0$ then loses stability at

$$z_c = \frac{2}{K}. \tag{3}$$

In two dimensions the cubic invariant of the nematic tensor vanishes, so the mean-field transition is continuous and there is no hysteresis in equilibrium. A finite w rounds the transition into a crossover, as a field does in a magnet. Fluctuations in two dimensions destroy true long-range nematic order, and hard rods order through a Kosterlitz–Thouless transition [3, 7]. With $w > 0$ the rack frame removes the soft mode, which is the reason we use Eq. (2) and not a fluctuation theory.

C. Handedness

To first order in b, the mean of $\cos\phi$ over a nematic ensemble with order S_x is $\langle \cos^2 \phi \rangle\, b \langle s \rangle = \tfrac{1}{2}(1 + S_x)\, b\,(1 - 2 f_L)$, where f_L is the fraction of left-handed loaders. Hence

$$P_x = P_0\,(1 - 2 f_L), \qquad P_0 = \tfrac{1}{2}\,(1 + S_x)\, b. \tag{4}$$

The polar order vanishes at $f_L = 1/2$ by mirror symmetry, and reverses sign above it.

III. METHODS

A. Racks and users

We photographed 94 communal dish racks in the kitchens of three buildings of one institute. All were wire tray racks with the wires parallel to the long side. Rack footprints ranged from 760 to 2,080 cm^2. Each rack was used by 3 to 30 regular users (mean 16.4; 1,544 users in all), who signed up for it on a form that included a question on writing hand. One hundred and sixty users (10.4%) wrote with the left hand. We take f_L for each rack as the fraction of its listed users who are left-handed. The writing-hand question is the first item of the Edinburgh inventory [8]. The study was approved by the institute's committee on research involving staff (ref. WS-2026-031) and users were told that it concerned kitchen use.

B. Imaging

A camera on the cupboard above each rack took one image at 17:30 on each of 28 consecutive working days (4 May to 10 June 2026). Racks holding fewer than two mugs on a given day were skipped and replaced by a later day, so that every rack contributes 28 images and the data comprise 2,632 images of 20,251 mugs. Mugs without a handle, and mugs with two, were left out. The handle angle was the direction from the centre of the rim ellipse to the centroid of the handle, after rectifying the image against the rack frame. The standard deviation of the angle between two measurements of 60 mugs was 4°, which attenuates $\langle \cos 2\phi \rangle$ by 1%. The mug diameter used below is $D = 8.5$ cm, the median rim diameter of 120 mugs measured in the kitchens. We counted as a contact any pair whose rim centres were less than $1.5\,D$ apart, a range chosen before the analysis to include the handle and a thumb of clearance. The contact number z is the mean count per mug in each image, with no correction for the rack boundary.

C. Fits

Eq. (2) was fitted to S_x binned in z by least squares, with a floor of 0.005 added in quadrature to each standard error, solving the self-consistency condition numerically for each bin. Eq. (4) was fitted to the per-rack mean of P_x against f_L. Uncertainties are standard errors from the fit covariance and treat the 28 images of one rack as independent, which overstates the precision of any quantity that varies between racks.

IV. RESULTS

A. Orientation of the handles

Fig. 1 shows the distribution of ϕ for the 9,622 mugs in the 988 images with $z \geq 2.5$, which we call the dense racks. It has two maxima, at $\phi = 0$ and $\phi = \pm 180°$, so the handles lie along the rack axis. The two maxima are unequal. Within $30°$ of the right-pointing direction lie 33.5% of the handles, against 15.4% within $30°$ of the left-pointing direction, and 64.1% point into the right half-plane. A uniform distribution would put 16.7% in each window.

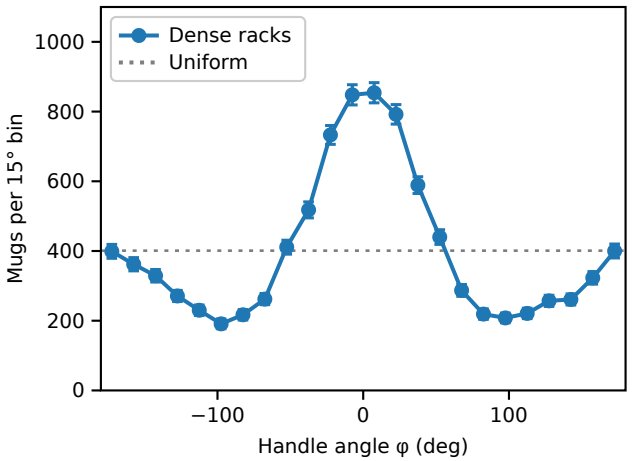


FIG. 1. Distribution of handle angle for the 9,622 mugs in dense racks (contact number of 2.5 or more), in 15 degree bins. Error bars are the square root of the count. The dotted line is the uniform expectation. Zero degrees is a handle pointing to the right of a person facing the rack.

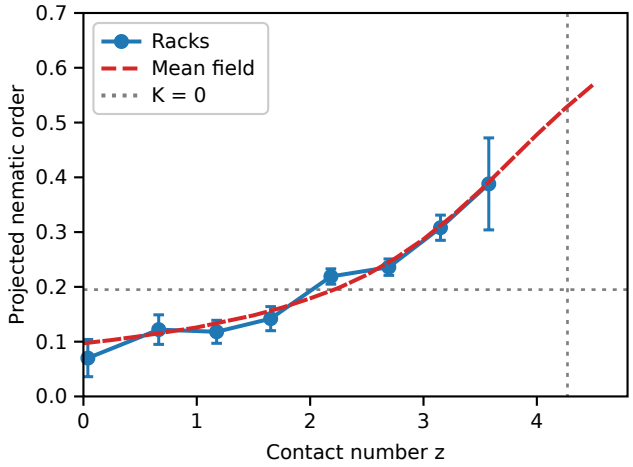


FIG. 2. Projection of the nematic order on the rack axis against contact number, for all 2,632 images, binned in contact number. Error bars are standard errors. The dashed curve is the mean-field solution with the fitted coupling and anchoring. The dotted horizontal line is the anchoring-only solution. The vertical dotted line marks the extrapolated critical contact number.

B. Nematic order against coordination

Averaged over all images, $S_x = 0.198 \pm 0.008$ and $P_x = 0.229 \pm 0.006$ (Table I). The nematic order grows with the contact number. Fig. 2 shows S_x rising from 0.07 ± 0.03 for racks with almost no contacts ($z < 0.5$) to 0.31 ± 0.02 at $z = 3.2$ and 0.39 ± 0.08 in the last bin ($z = 3.6$, 32 images). The sparsest racks are dominated by counting noise. For handles oriented independently and uniformly, S_x has a standard deviation of $(2N)^{-1/2}$, which is 0.36 for the mean $N = 3.8$ of the images with $z < 1$. We observe 0.41.

TABLE I. Racks by footprint tercile. N is the number of mugs per image, z the contact number. Standard errors of the last digits in parentheses.

Footprint (cm^2)	Racks	$\langle N \rangle$	$\langle z \rangle$	$\langle S_x \rangle$	$\langle P_x \rangle$
760–1,160	31	6.9	2.26	0.209(14)	0.221(10)
1,160–1,440	31	7.6	1.98	0.192(13)	0.225(11)
1,440–2,080	32	8.6	1.77	0.192(12)	0.240(10)
All	94	7.7	2.00	0.198(8)	0.229(6)

Anchoring to the rack axis alone, with $K = 0$, gives a constant $S_x = 0.195$ and describes the data poorly ($\chi^2 = 54.5$ for 7 degrees of freedom). Including the coupling, Eq. (2) fits with $K = 0.469 \pm 0.036$ and $w = 0.196 \pm 0.023$, $\chi^2 = 3.3$ for 6 degrees of freedom (Table II). The critical contact number of Eq. (3) is $z_c = 4.3 \pm 0.3$, and S_x at that point is 0.53.

The fit extends to $z = 4.5$ in Fig. 2, which is beyond the data. The largest contact number in the sample is 3.87, and 0.8% of the images have $z > 3.5$. In the usual two-dimensional counting, an isostatic packing of frictionless disks has $z = 2d = 4$ [9, 10]. A rack whose mugs all touch their neighbours with $z \approx 4$ has, roughly speaking, no room for another. The fitted z_c is within one standard error of this value.

TABLE II. Fit parameters. Mean-field fit to the eight bins of the nematic-order figure; anchoring-only fit ($K = 0$); one-parameter polar fit to the 94 per-rack means of P_x; and the straight line $P_x = a + c f_L$ with its zero crossing. The bias b follows from P_0 and the mean S_x through the polar relation.

Fit	Parameters	χ^2/dof
Mean field	$K = 0.469(36)$, $w = 0.196(23)$, $z_c = 4.3(3)$	3.3/6
$K = 0$	$w = 0.397(20)$	54.5/7
Polar	$P_0 = 0.283(8)$, $b = 0.47(1)$	rms 0.064
Line	$a = 0.269(10)$, $c = -0.400(79)$, zero at $f_L = 0.67(11)$	

C. Dependence on rack size

Racks of different footprint reach different contact numbers for the same number of mugs (Table I), and a coupling between neighbours should depend on z and not on N or on the footprint. We therefore fitted Eq. (2) separately to the three footprint terciles, in five bins of z each (Table III). The couplings are 0.44 ± 0.08, 0.49 ± 0.06 and 0.52 ± 0.04, which agree with

each other and with the pooled value, and the anchoring strengths agree as well. The critical contact number moves from 4.6 ± 0.8 in the smallest racks to 3.8 ± 0.3 in the largest. That follows the trend in K and is not significant (0.9 standard deviations between the extremes). Two of the three fits have a χ^2 above its expectation, 9.6 and 6.6 for 3 degrees of freedom. We have no explanation beyond the possibility that the error floor of 0.005 is too small for the sparsely populated bins.

TABLE III. Mean-field fits to each footprint tercile separately, in five bins of z.

Footprint (cm^2)	K	w	z_c	χ^2/dof
760–1,160	0.437(78)	0.209(49)	4.6(8)	9.6/3
1,160–1,440	0.488(56)	0.184(36)	4.1(5)	3.2/3
1,440–2,080	0.522(40)	0.175(29)	3.8(3)	6.6/3

D. Correlation between neighbours

Fig. 3 shows the pair correlation $C(r) = \langle \cos 2(\phi_i - \phi_j) \rangle$ for pairs at separation r. It is 0.47 in the two bins inside $1.5\,D$ and falls to 0.18 ± 0.01 in the next one. Beyond that point it stays between 0.13 and 0.24 out to $3\,D$ with no systematic decay. The step at $1.5\,D$ is the range that we used to define a contact, which was chosen before the analysis, and we take it as support for that choice. The residual correlation at larger distances comes in part from the common alignment with the rack axis, for which $S_x^2 \approx 0.04$ is too small to account for the whole of it, and in part from chains of contacts. We did not separate the two.

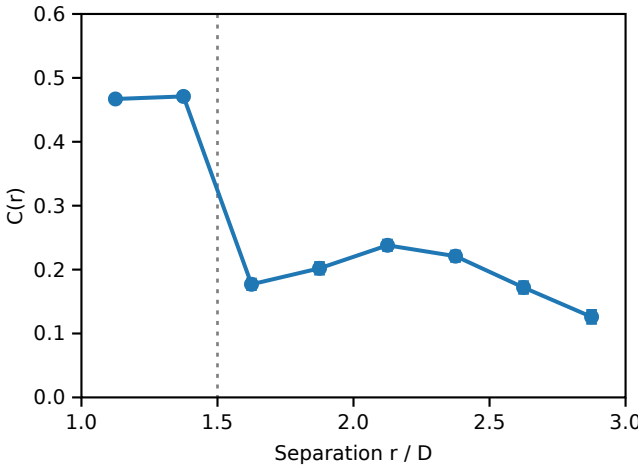


FIG. 3. Orientational pair correlation against the separation of rim centres in units of the mug diameter, for all pairs in all images. Error bars are standard errors. The dotted vertical line marks the contact range of 1.5 diameters.

E. Handedness and polar order

The polar order of a rack falls as the fraction of left-handed users rises (Fig. 4). A straight line through the 94 per-rack means has slope -0.40 ± 0.08 and intercept 0.269 ± 0.010, and crosses zero at $f_L = 0.67 \pm 0.11$, which is compatible with the $1/2$ required by mirror symmetry. The one-parameter form Eq. (4), which has this zero built in, gives $P_0 = 0.283 \pm 0.008$ with an rms residual of 0.064 per rack. With $\langle S_x \rangle = 0.198$ this corresponds to $b = 0.47 \pm 0.01$. No rack had f_L above 0.40, so the reversal itself was not observed.

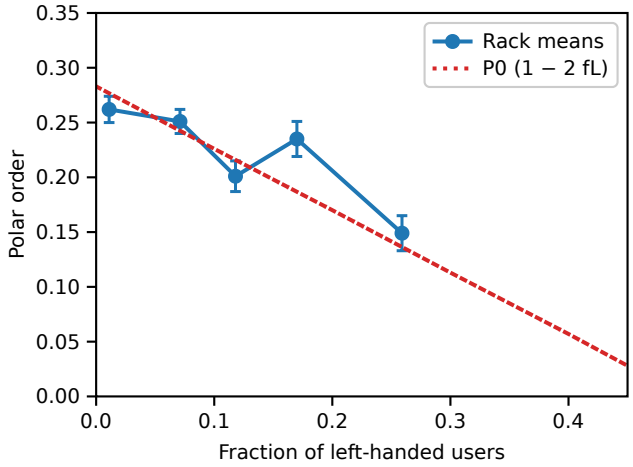


FIG. 4. Mean polar order of each rack, averaged in bins of the fraction of left-handed users (28, 18, 23, 15 and 10 racks from left to right; 94 racks in all). Error bars are standard errors over racks. The dotted line is the one-parameter relation with a polar amplitude of 0.283.

V. DISCUSSION

The handles of mugs on a communal rack are not isotropic. They lie along the rack axis, they lean to the right, and the lean decreases with the fraction of left-handed users in the way mirror symmetry requires. A mean-field model with a pair coupling, an anchoring to the rack frame and a handedness field accounts for the z dependence of the nematic order and for the polar order with three fitted parameters, and the fit to $S_x(z)$ is good.

The transition itself is out of reach. The rack leaves the isotropic state at $z_c = 4.3 \pm 0.3$ in the model, and the racks stop accepting mugs at about $z = 4$. Under this analysis the ordered phase and the jammed state are the same state, and a rack can be observed approaching one but not in it. This does not tell us whether the coincidence has a cause. The fitted K is an effective value that absorbs fluctuations the mean-field theory does not treat, and an error of 10% in K moves z_c across the isostatic value. To test the prediction one

would need a rack that continues to accept mugs after the contact network is jammed. A two-layer arrangement would do it, but it would no longer be two-dimensional.

Several limitations apply. The racks are all of one construction, the mugs have one handle, and the kitchens belong to one institute. The coupling K and the contact range were determined from the same images, so $C(r)$ supports the range only in the sense that the data are consistent with it. The standard errors treat images of a rack as independent although the rack's users and geometry are shared across the 28 days. Self-reported writing hand is a coarse proxy for the hand that places a mug, and mugs are also loaded by cleaners and by visitors.

Two things would settle most of what is open here. A rack with f_L above one half would show the reversal of the polar order and give an independent estimate of b. And a nematic order parameter tensor in place of S_x would show whether the director follows the rack axis everywhere or only on average, which the projected measure cannot distinguish.

ACKNOWLEDGMENTS

We thank the 1,544 kitchen users for signing the form, the facilities department of the Halloran Institute for access to the kitchens, and the two annotators who checked the handle angles. This work was supported by the Karrebæk Foundation for Applied Physics (grant KF-25-117).

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