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Random Convex Hulls: Applications to Ecology and Animal Epidemics

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Random Convex Hulls: Applications to Ecology and Animal Epidemics

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Plan:

- Random Convex Hull $\Longrightarrow$ definition
- Convex Hull of two-dimensional stochastic processes

  simple random walks, branching random walks etc.

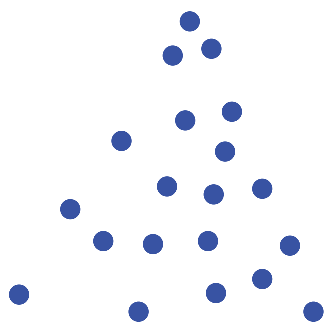
- Motivation $\Longrightarrow$ an ecological problem and animal epidemics
- Cauchy's formulae for perimeter and area of a closed convex curve in two dimensions

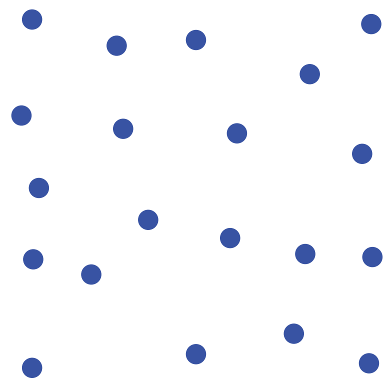
  $\Longrightarrow$ applied to random convex polygon

  $\Longrightarrow$ link to Extreme Value Statistics

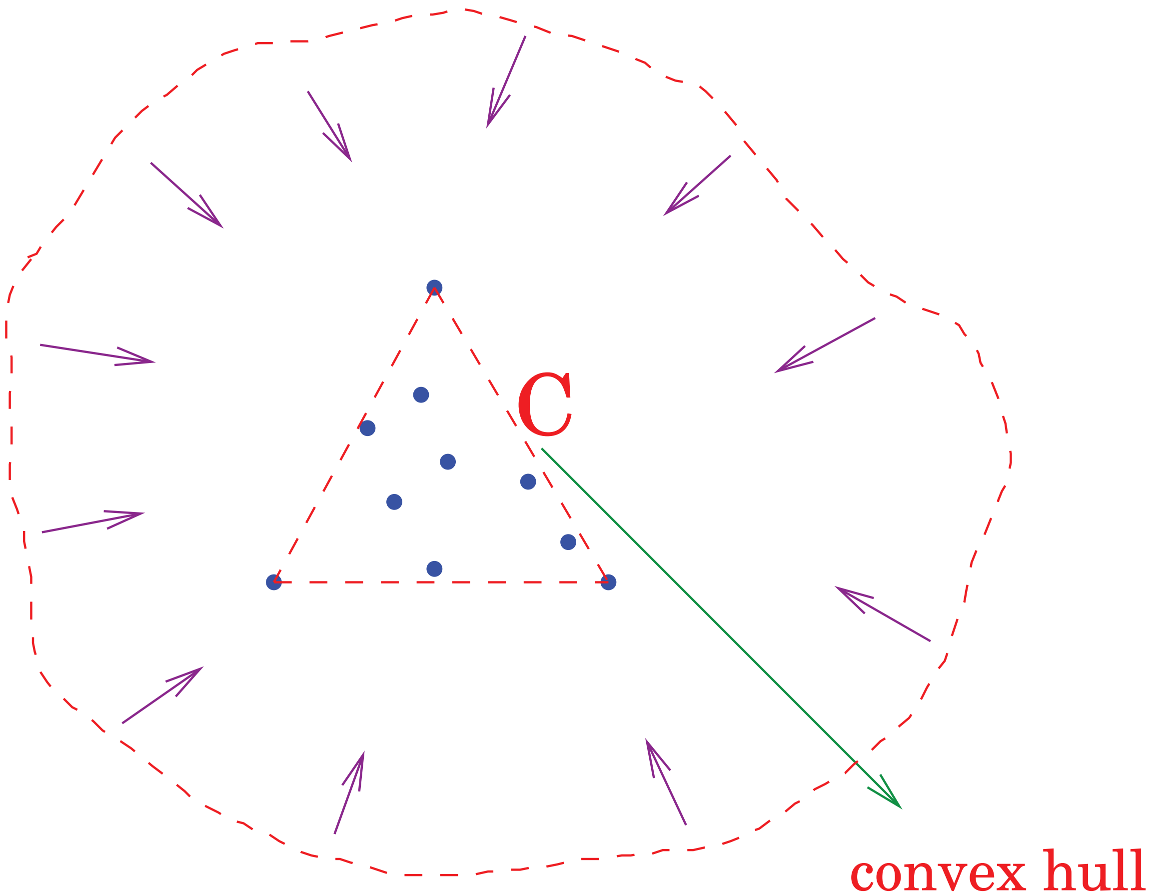
- Exact results for the mean perimeter and the mean area of convex hulls
- Summary and Conclusion

Shape of a set of Points

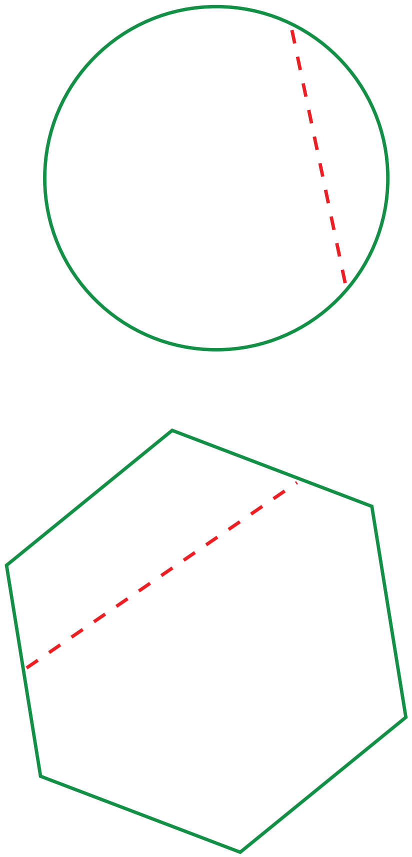




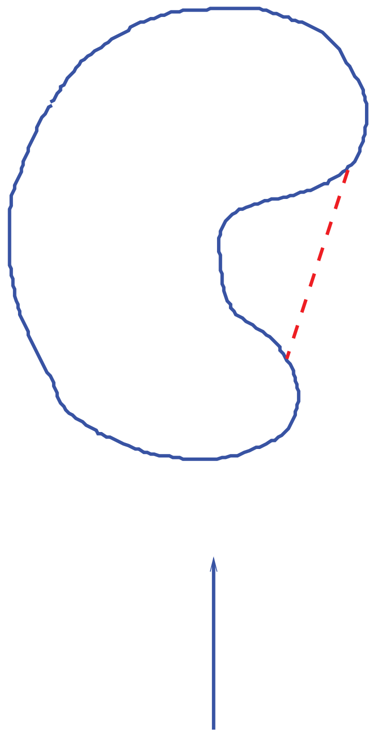
Shape of a set of Points: Convex Hull



Closed Convex Curves

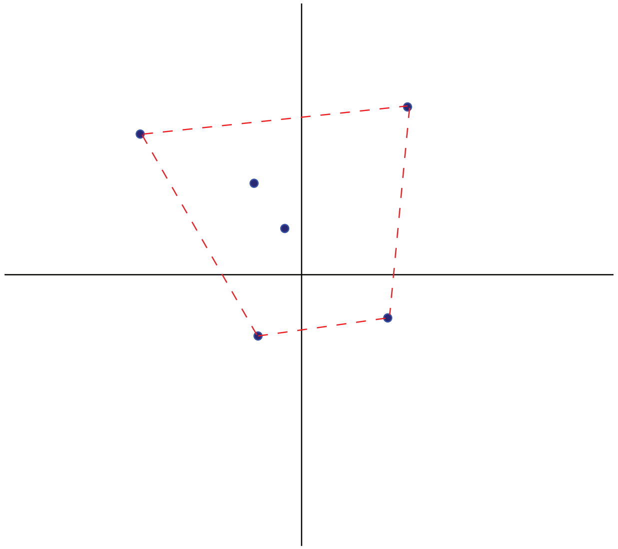


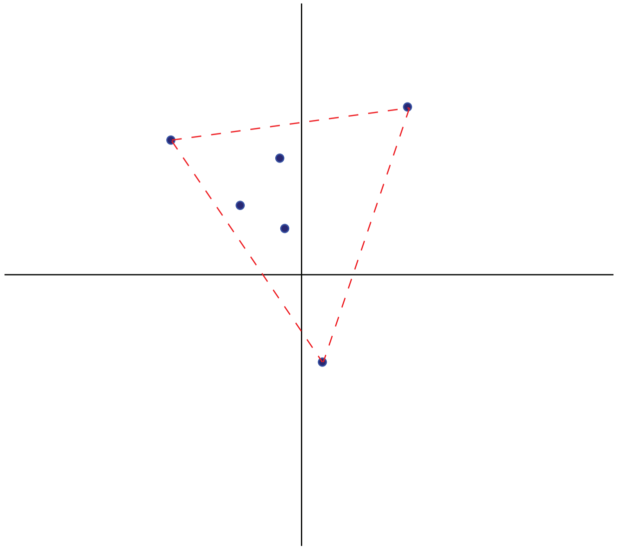
CONVEX



NON–CONVEX

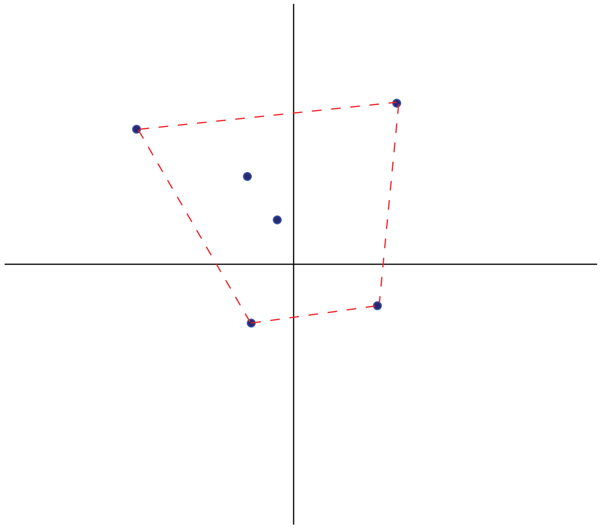
Random Convex Hull in a Plane





- Convex Hull $\Longrightarrow$ Minimal convex polygon enclosing the set
- The shape of the convex hull $\rightarrow$ different for each sample
- Points drawn from a distribution $P\left(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N\right)$
  $\rightarrow$ Independent or Correlated
- Question: Statistics of observables: perimeter, area and no. of vertices

Independent Points in a Plane



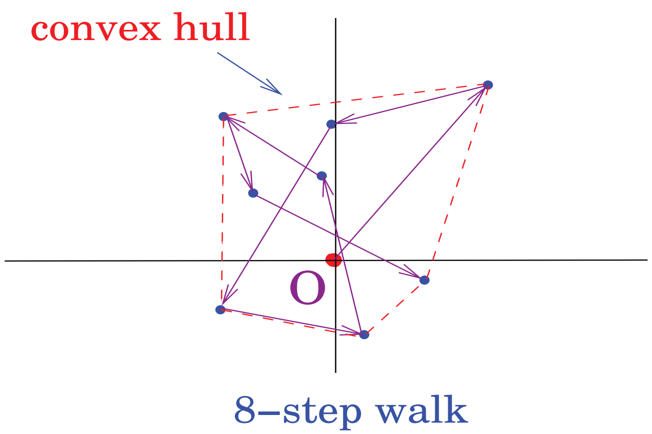
Each point chosen independently from the same distribution

$$P\left(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N\right) = \prod_{i=1}^{N} p(\vec{r}_i)$$

Associated Random Convex Hull $\longrightarrow$ well studied by diverse methods

Lévy ('48), Geffroy ('59), Spitzer & Widom ('59), Baxter ('59)
Rényi & Sulanke ('63), Efron ('65), Molchanov ('07)....many others

Correlated Points: Open Random Walk



Discrete-time random Walk of N steps

$x_k = x_{k-1} + \xi_x(k)$
$y_k = y_{k-1} + \xi_y(k)$

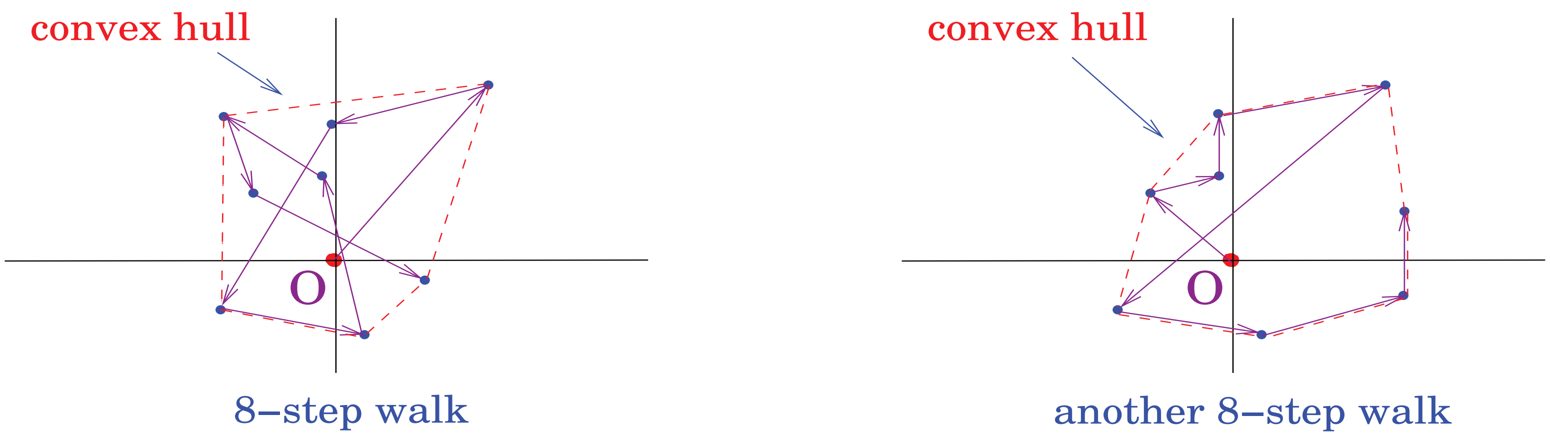
$\xi_x(k), \xi_y(k) \to$ Independent jump lengths

Continuous-time limit: Brownian path of duration T

$$\frac{dx}{d\tau} = \eta_x(\tau)$$
$$\frac{dy}{d\tau} = \eta_y(\tau)$$

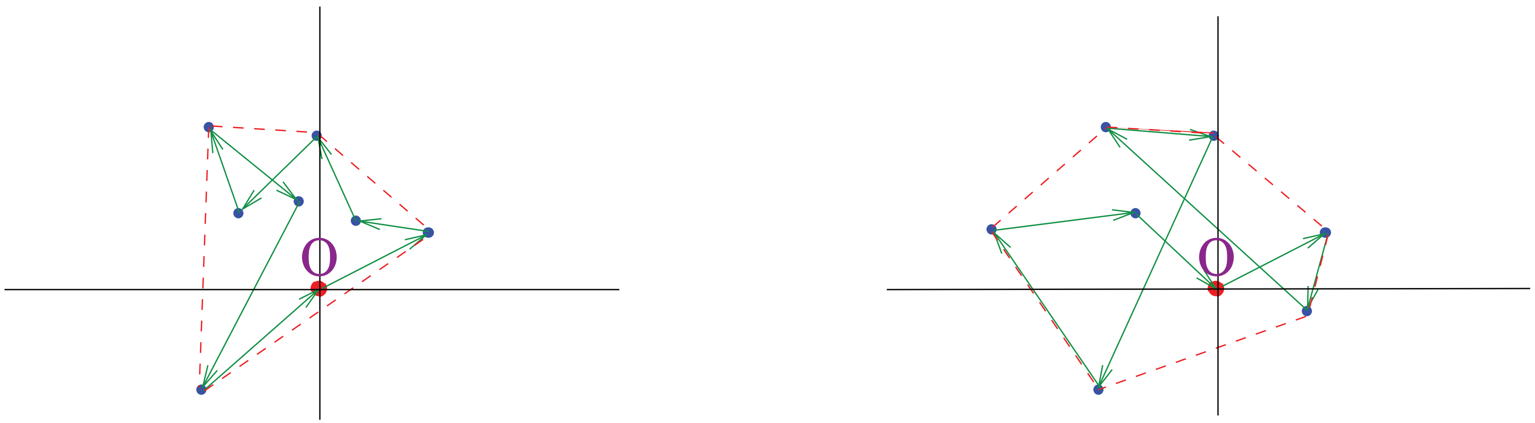
$$\langle \eta_x(\tau)\eta_x(\tau')\rangle = 2\,D\,\delta(\tau-\tau')$$
$$\langle \eta_y(\tau)\eta_y(\tau')\rangle = 2\,D\,\delta(\tau-\tau')$$
$$\langle \eta_x(\tau)\eta_y(\tau')\rangle = 0$$

Correlated Points: Open Random Walk



- Continuous-time limit: Brownian path of duration T
- mean perimeter and mean area of the associated Convex hull?
- mean perimeter: $\langle L_1 \rangle = \sqrt{8\pi}\,\sqrt{2\,D\,T}$ (Takács, '80)
- mean area: $\langle A_1 \rangle = \frac{\pi}{2}\,(2\,D\,T)$ (El Bachir, '83, Letac '93)

Correlated Points: Closed Random Walk



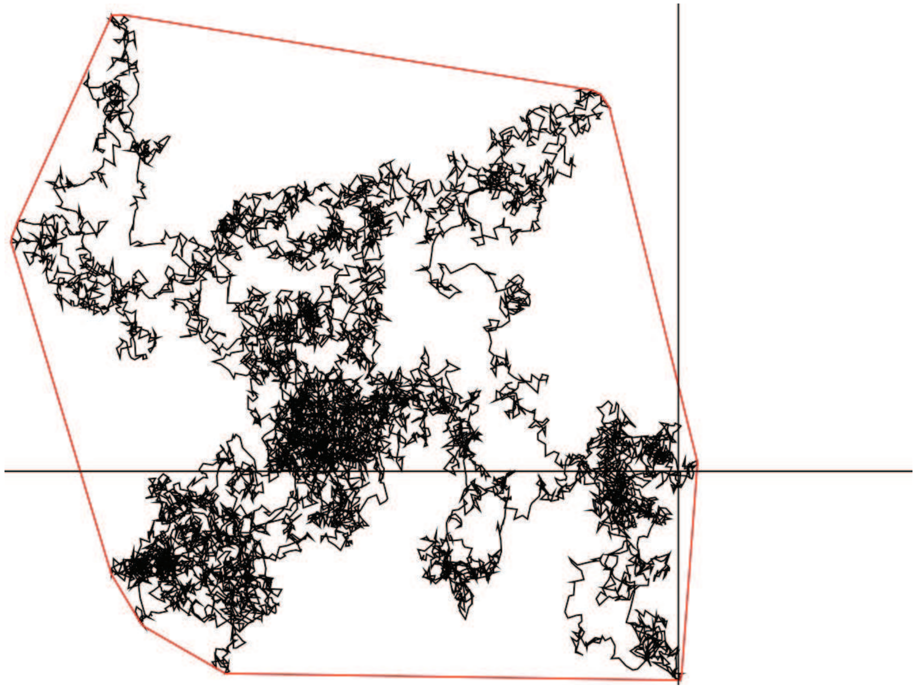
8 step random bridge   another 8 step bridge

• Continuous-time limit: Brownian bridge of duration T : starting at O and returning to it after time T

• mean perimeter: $\langle L_1 \rangle = \sqrt{\frac{\pi^3}{2}}\sqrt{2\,D\,T}$ (Goldman, '96).

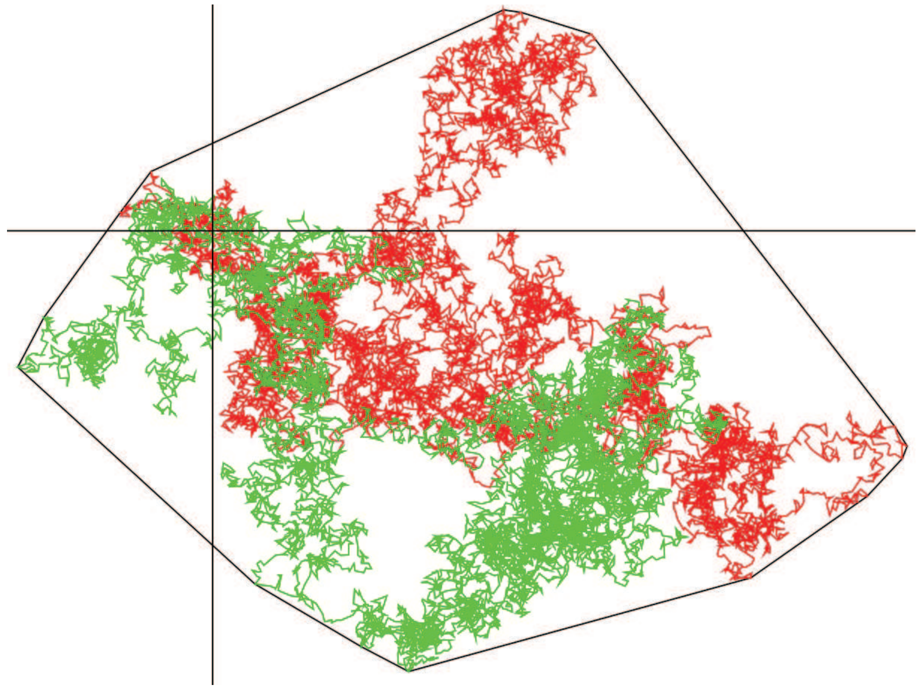
• mean area: $\langle A_1 \rangle = (?)\,(2\,D\,T)$

Home Range Estimate via Convex Hull



Models of home range for animal movement, Worton (1987)
Integrating Scientific Methods with Habitat Conservation Planning, Murphy and Noon (1992)
Theory of home range estimation from displacement measurements of animal populations, Giuggioli et. al. (2005)
Home Range Estimates, Boyle et. al., (2009)

Home Range Estimate via Convex Hull



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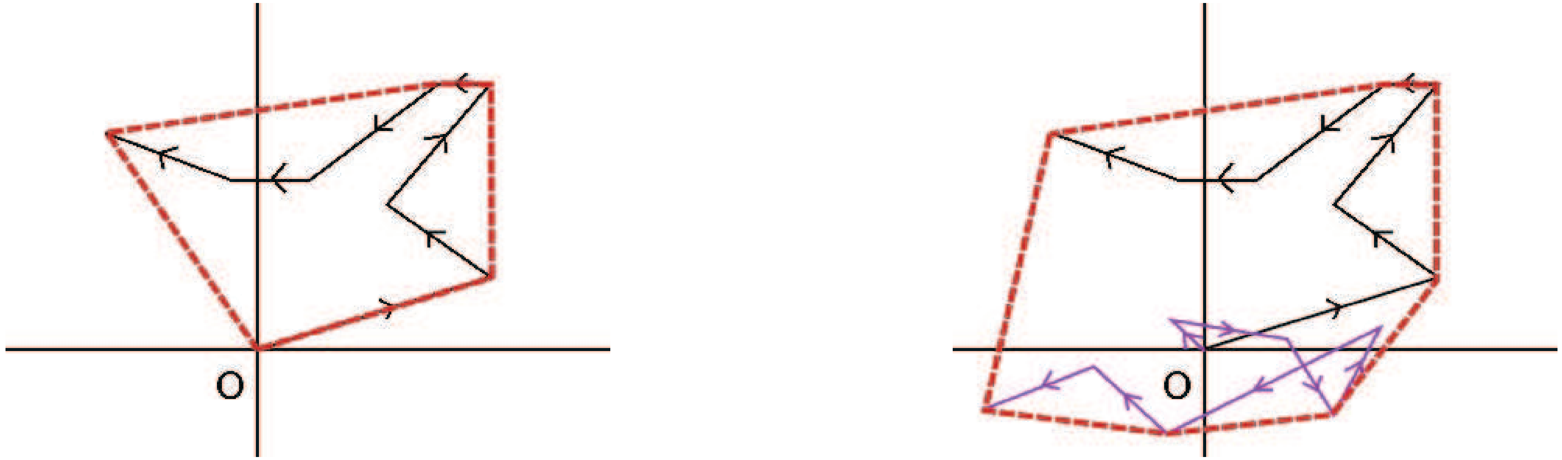
Global Convex Hull of n Independent Brownian Paths



• Mean perimeter $\langle L_n \rangle$ and mean area $\langle A_n \rangle$ of n independent Brownian paths (bridges) each of duration T?

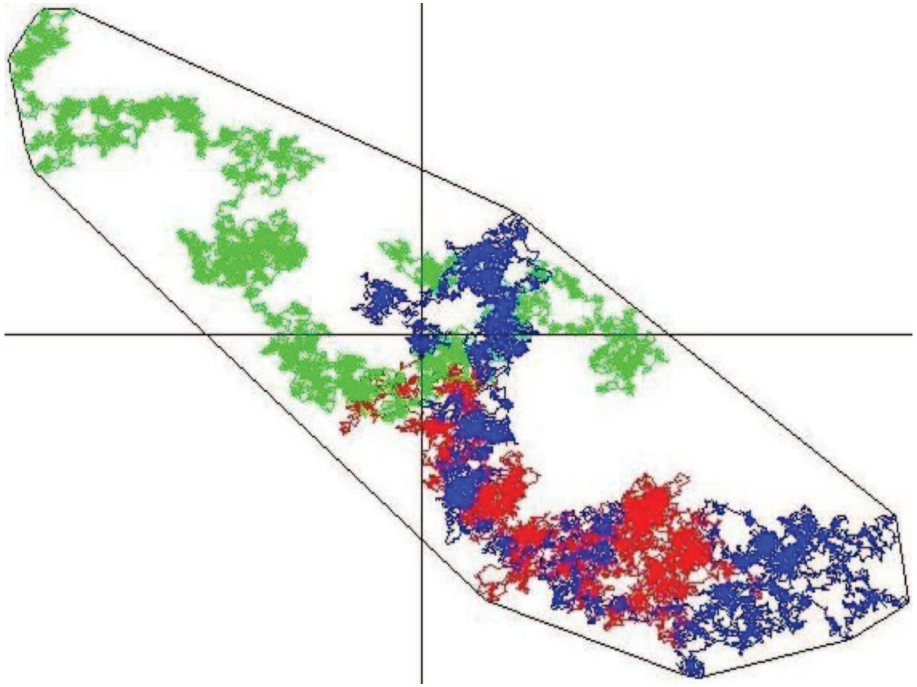
• $\langle L_n \rangle = \alpha_n \sqrt{2\,D\,T}$; $\langle A_n \rangle = \beta_n\,(2\,D\,T)$

• Recall $\boxed{\alpha_1 = \sqrt{8\pi}, \quad \beta_1 = \pi/2}$ (open path)

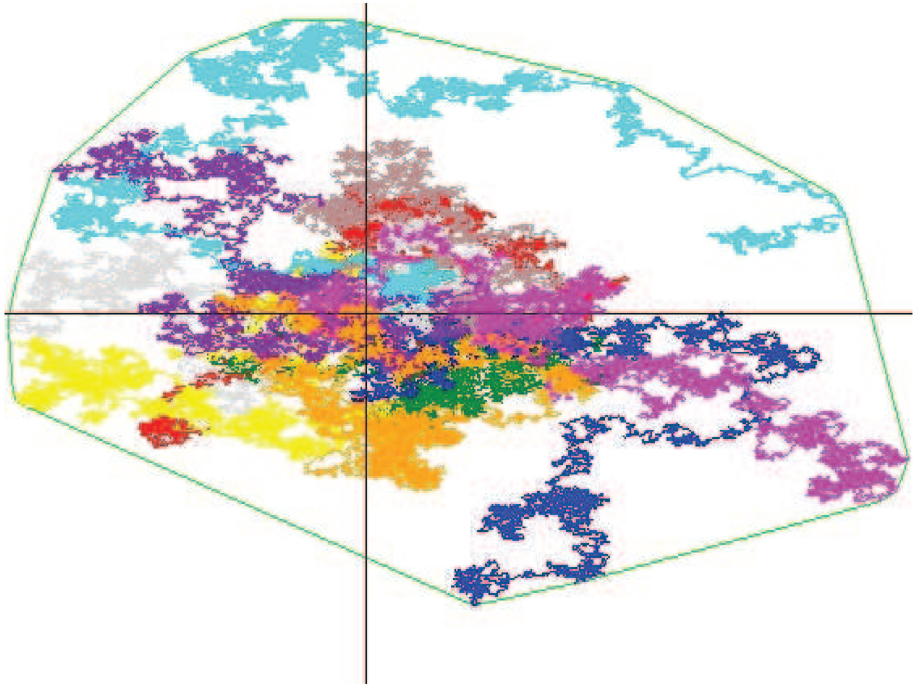
$\boxed{\alpha_1 = \sqrt{\pi^3/2}, \quad \beta_1 = ?}$ (closed path)

• $\boxed{\alpha_n, \quad \beta_n = ?}$ $\rightarrow$ both for open and closed paths $\rightarrow$ n-dependence?

Global Convex Hull of n Independent Brownian Paths



$n = 3$ closed paths



$n = 10$ open paths

Outbreak of animal epidemics

Preventive Veterinary Medicine 92 (2009) 60–70

Contents lists available at ScienceDirect

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PREVENTIVE VETERINARY MEDICINE

The equine influenza epidemic in Australia: Spatial and temporal descriptive analyses of a large propagating epidemic

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[b] Faculty of Veterinary Science, The University of Sydney, Private Mail Bag 3, Camden, NSW 2570, Australia

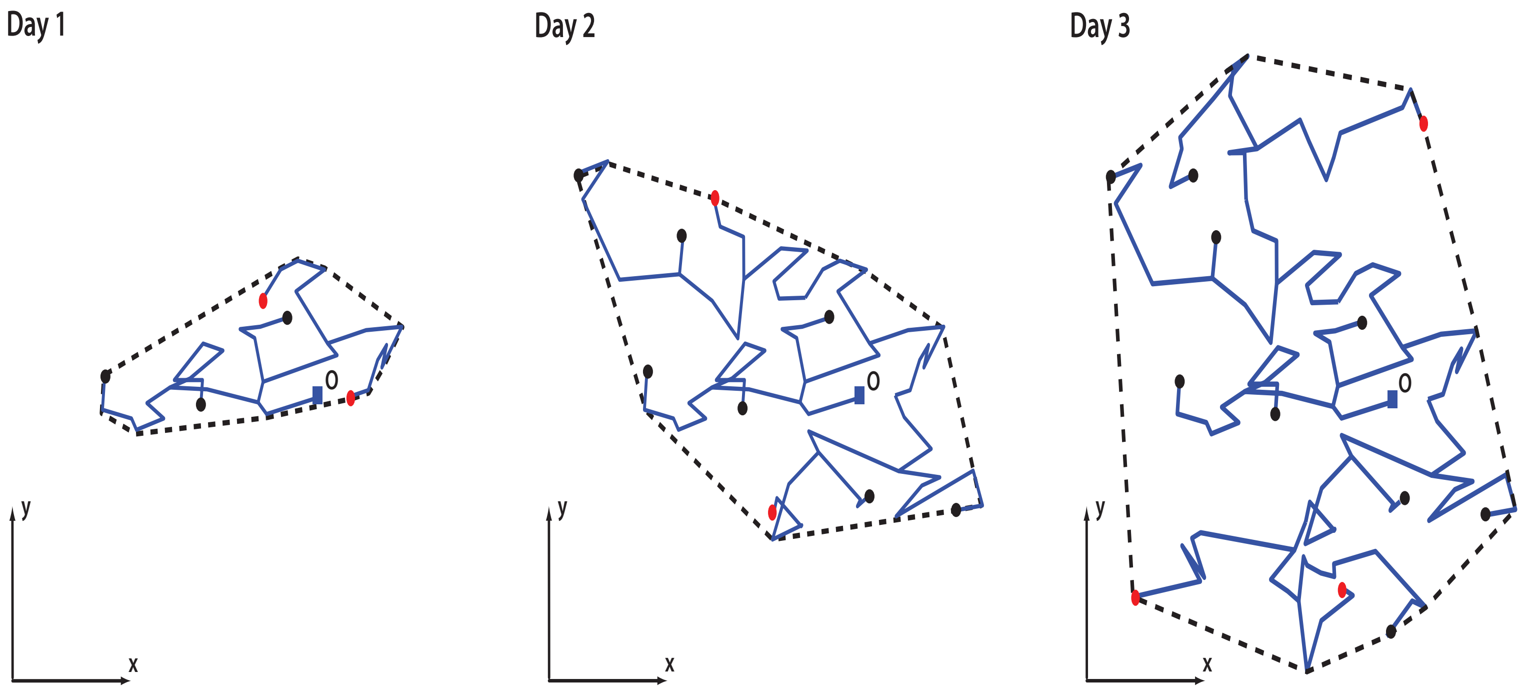
Outbreak of animal epidemics

B. Cowled et al. / Preventive Veterinary Medicine 92 (2009) 60–70

2.4. Spatial and temporal overview of the epidemic

An epidemic curve was created by plotting the number of premises on which equids first displayed clinical signs for each day of the epidemic on the *Y* axis, and day of the epidemic on the *X* axis. The day clinical signs were first reported was used, rather than the date of confirmation of diagnosis to avoid reporting bias (Gibbens and Wilesmith, 2002). The change in the size of the infected area over time was also calculated. The area infected was estimated by creating a minimum convex hull (MCH) that encompassed all infected premises for every 2 days of the epidemic. A MCH is a convex polygon which encompasses a collection of point locations (Mapinfo Coorporation, 2006). The increase in the infected area from one 2-day time period

Outbreak of animal epidemics



animal epidemic spread $\Longrightarrow$ branching (infection) [with rate b] Brownian motion with death (recovery) [with rate a]

- supercritical: $b > a \to$ epidemic explodes
- subcritical: $b < a \to$ epidemic becomes extinct
- critical: $b = a \to$ epidemic critical

Q: how does the perimeter and area of the convex hull grow with time t?

Two problems in 2-d

Perimeter and Area of the convex hull in two different 2-d problems:

I. convex hull of n independent Brownian motions of duration T

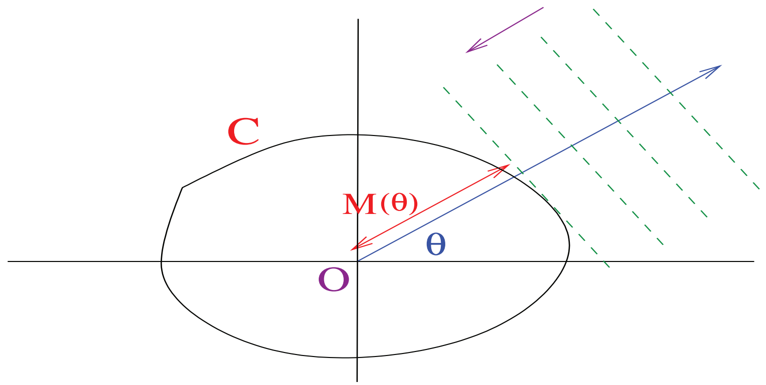
$\Longrightarrow$ home range estimate

II. convex hull of a branching Brownian motion with death

$\Longrightarrow$ spread of animal epidemics

- Numerical simulations $\longrightarrow$ relatively easy
- Analytical computation $\longrightarrow$ how to proceed?

Cauchy's Formulae for a Closed Convex Curve



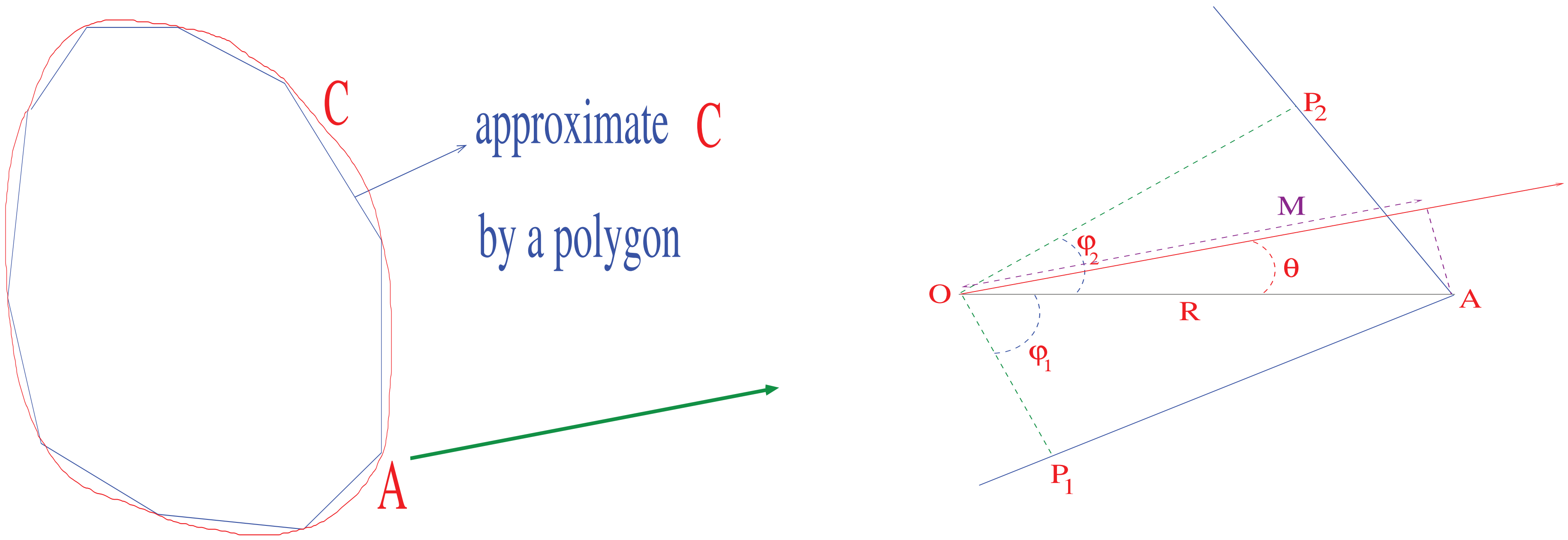
- For any point $[X(s), Y(s)]$ on C define:

Support function: $M(\theta) = \max_{s \in C} [X(s)\cos(\theta) + Y(s)\sin(\theta)]$

- Perimeter: $$L = \int_0^{2\pi} d\theta \; M(\theta)$$ (A. Cauchy, 1832)

- Area: $$A = \frac{1}{2}\int_0^{2\pi} d\theta \; \left[M^2(\theta) - [M'(\theta)]^2\right]$$

A simple physicist's proof of Cauchy's formula



$$M(\theta) = R\cos\theta$$

Perimeter: $\int_{-\phi_1}^{\phi_2} M(\theta)d\theta = R\left[\sin(\phi_1) + \sin(\phi_2)\right] = L_{P_1AP_2}$

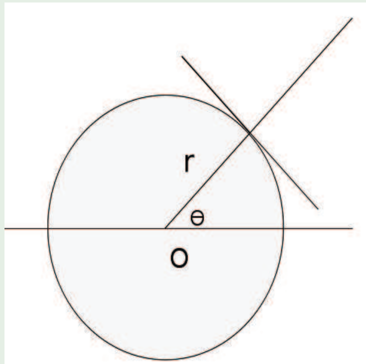
Area: $\frac{1}{2}\int_{-\phi_1}^{\phi_2}\left[M^2(\theta) - (M'(\theta))^2\right]d\theta$

$= \frac{R^2}{2}\left[\sin(\phi_2)\cos(\phi_2) + \sin(\phi_1)\cos(\phi_1)\right] = A_{OP_1AP_2}$

Examples

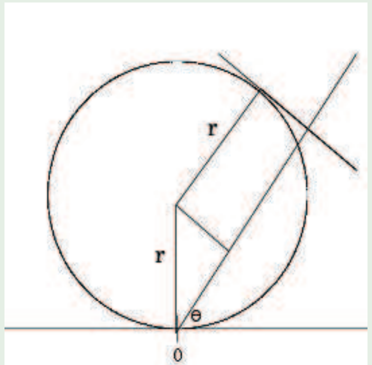
a circle centered at the origin:

$$M(\theta) = r$$



a circle touching the origin:

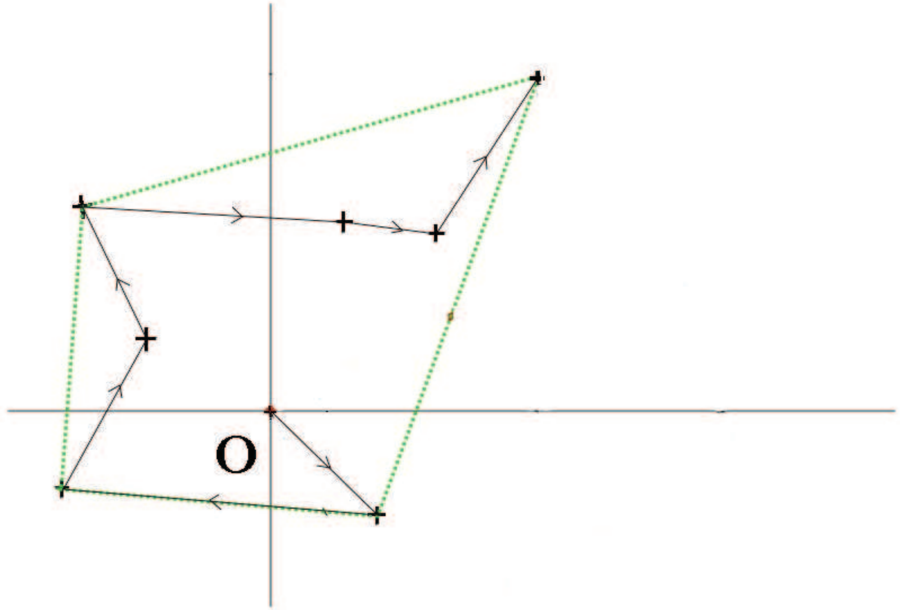
$$M(\theta) = r(1 + \sin\theta)$$



$$L = \int_0^{2\pi} d\theta\ M(\theta) = 2\pi r$$

$$A = \frac{1}{2}\int_0^{2\pi} d\theta\ \left[M^2(\theta) - [M'(\theta)]^2\right] = \pi r^2$$

Cauchy's formulae Applied to Convex Polygon

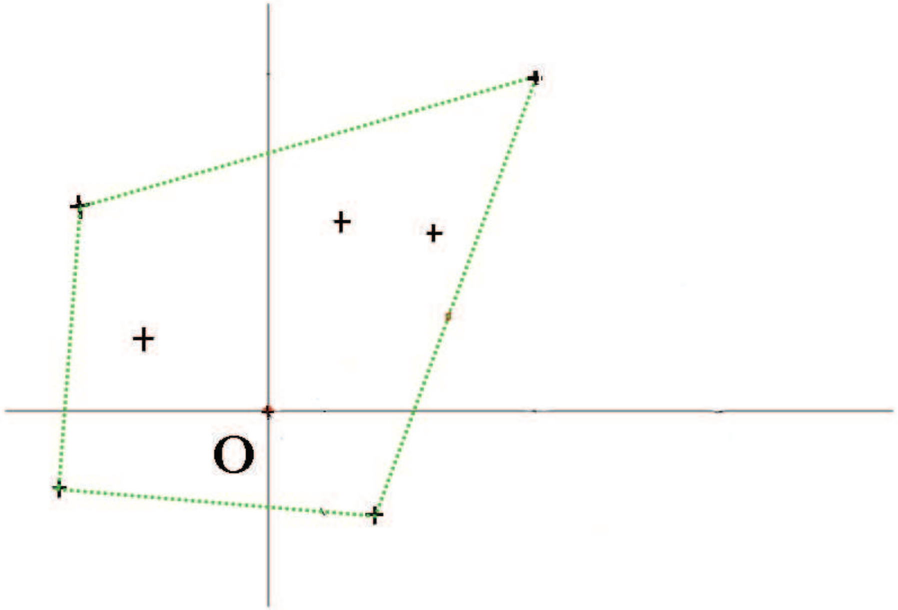


Consider an arbitrary stochastic process starting at O

Let $(x_k, y_k) \Longrightarrow$ vertices of the N-step walk

Let C (green) be the associated Convex Hull

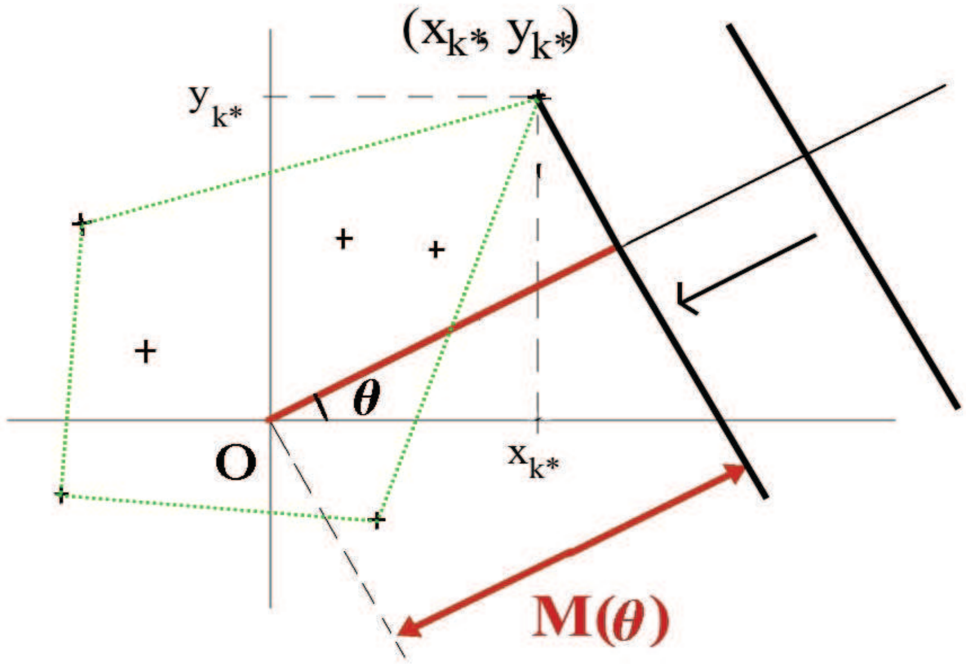
Cauchy's formulae Applied to Convex Polygon



$(x_k, y_k) \Longrightarrow$ vertices of the walk

$C \rightarrow$ Convex Hull with coordinates $\{X(s), Y(s)\}$ on C

Cauchy's formulae Applied to Convex Polygon



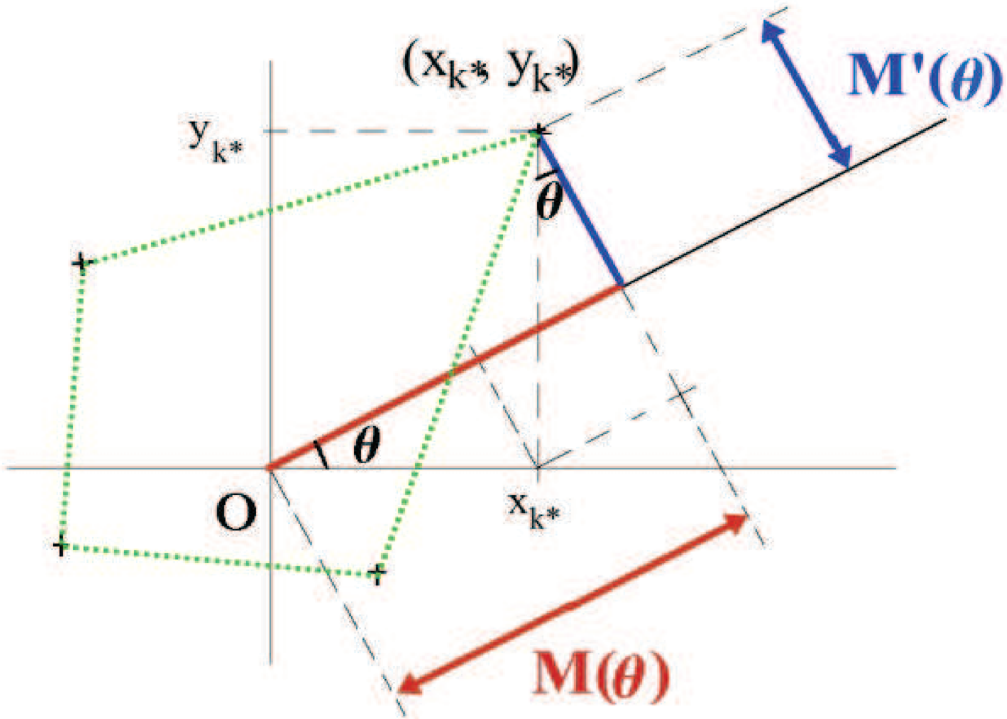
$$M(\theta) = \max_{s \in C} [X(s)\cos\theta + Y(s)\sin\theta]$$

$$= \max_{k \in I} [x_k \cos\theta + y_k \sin\theta]$$

$$= x_{k^*} \cos\theta + y_{k^*} \sin\theta$$

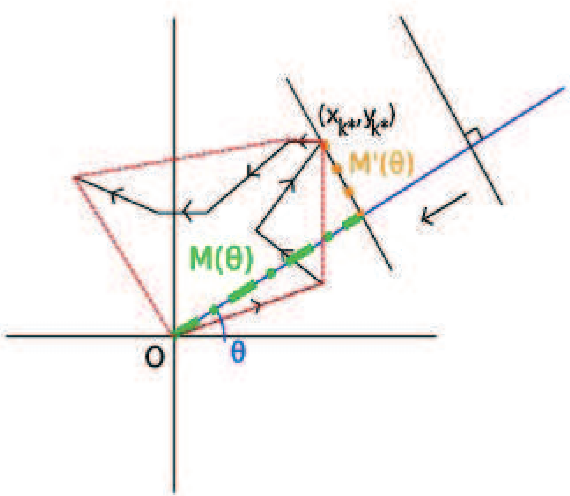
$k^* \rightarrow$ label of the point with largest projection along θ

Support Function of a Convex Hull



$$M(\theta) = x_{k^*}\cos\theta + y_{k^*}\sin\theta$$
$$M'(\theta) = -x_{k^*}\sin\theta + y_{k^*}\cos\theta$$

Cauchy's Formulae Applied to Random Convex Hull



Mean perimeter of a random convex polygon

$$\langle L \rangle = \int_0^{2\pi} d\theta \, \langle M(\theta) \rangle$$

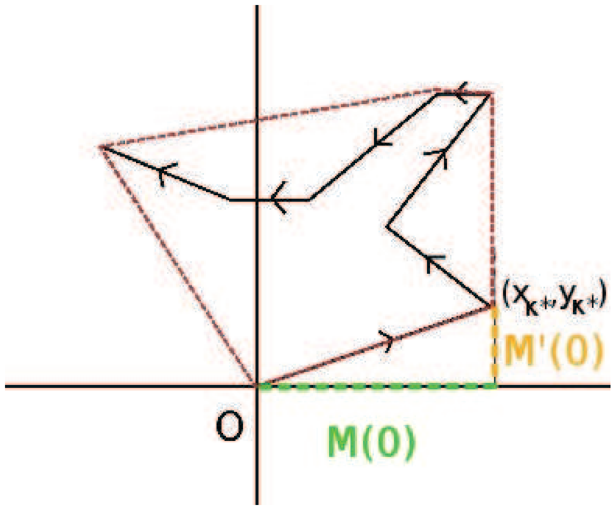
with $M(\theta) = x_{k^*} \cos\theta + y_{k^*} \sin\theta$

Mean area of a random convex polygon

$$\langle A \rangle = \frac{1}{2} \int_0^{2\pi} d\theta \left[\langle M^2(\theta) \rangle - \langle [M'(\theta)]^2 \rangle \right]$$

with $M'(\theta) = -x_{k^*} \sin\theta + y_{k^*} \cos\theta$

Isotropically Distributed Vertices



Mean Perimeter

$$\langle L\rangle = 2\pi \langle M(0)\rangle$$

with $M(\theta=0) = \max_{k\in I}\{x_k\} = x_{k^*}$

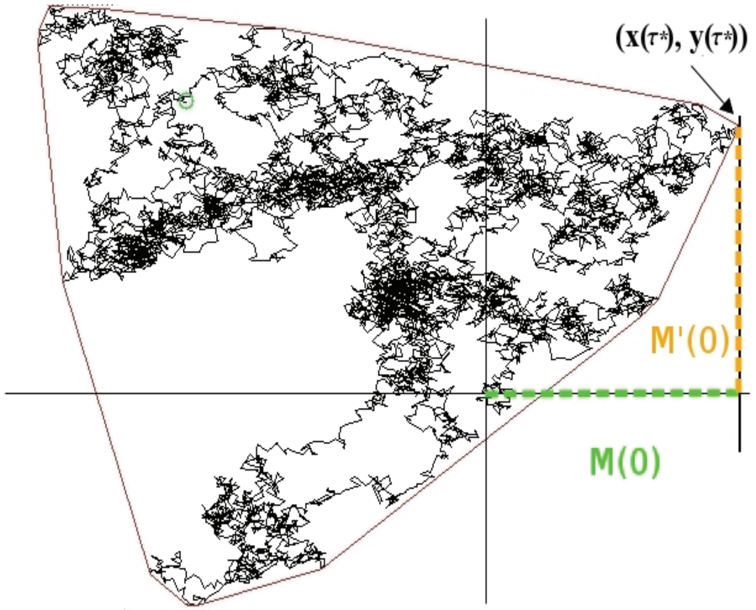
Mean Area

$$\langle A\rangle = \pi \left[\langle M^2(0)\rangle - \langle [M'(0)]^2\rangle\right]$$

with $M'(\theta=0) = y_{k^*}$

$\Longrightarrow$ Link to Extreme Value Statistics

Continuum limit



$x(\tau)$, $y(\tau)$ $\rightarrow$ a pair of independent one-dimensional processes: $0 \leq \tau \leq T$

Mean Perimeter

$$\langle L \rangle = 2\pi \langle M(0) \rangle$$

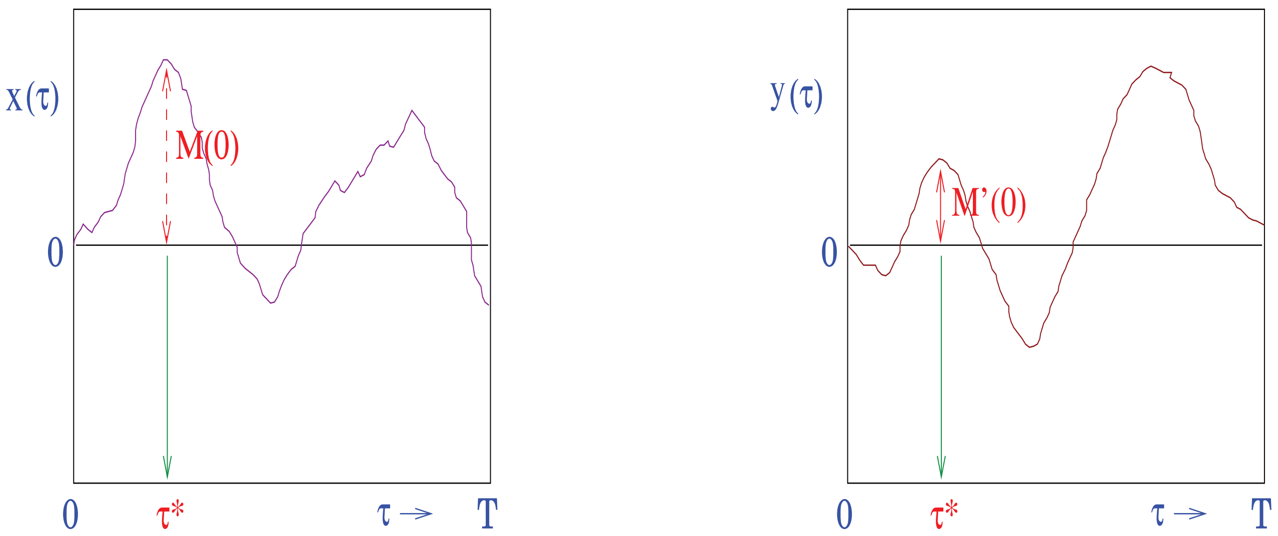
with $M(0) = \max_{0 \leq \tau \leq T} \{x(\tau)\} \equiv x(\tau^*)$

Mean Area

$$\langle A \rangle = \pi \left[\langle M^2(0) \rangle - \langle [M'(0)]^2 \rangle \right]$$

with $M'(0) = y(\tau^*)$

Interpretation of $M'(0)$

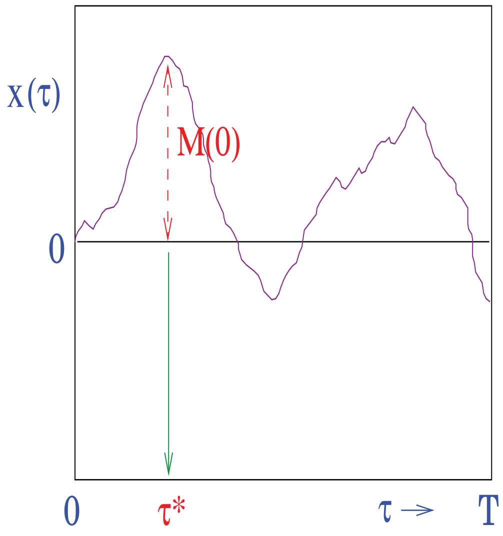


- $M(0) \rightarrow$ global maximum of $x(\tau)$ in $[0, T]$
- $M'(0) \equiv y(\tau^*)$ where $\tau^* \rightarrow$ time at which $x(\tau)$ is maximal in $[0, T]$

$$\Longrightarrow \langle [M'(0)]^2 \rangle = \langle y^2(\tau^*) \rangle$$

For diffusive processes: $\langle [M'(0)]^2 \rangle = 2\, D\, \langle \tau^* \rangle$

Reduction to 1-d extreme value problem



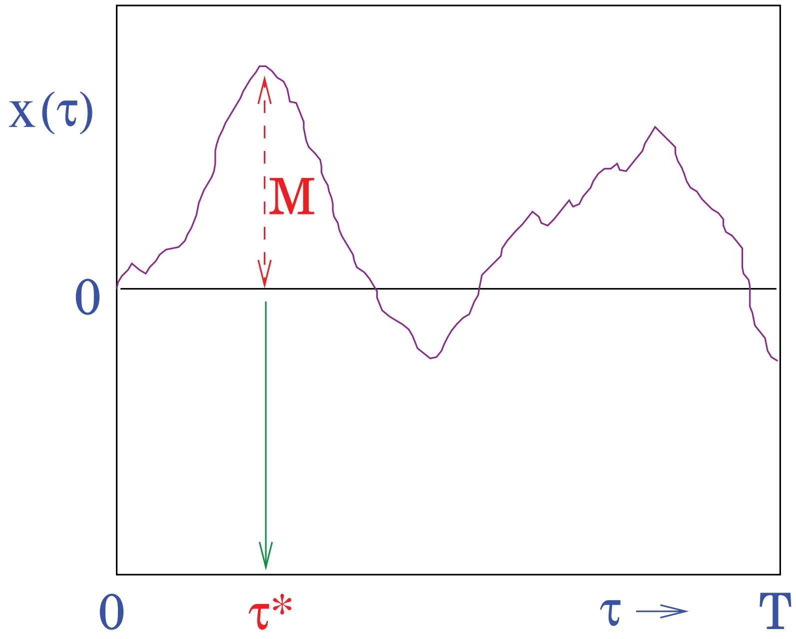
For arbitrary 2-d isotropic stochastic (diffusive) process

- Mean perimeter: $\langle L \rangle = 2\pi \, \langle M(0) \rangle$
- Mean area: $\langle A \rangle = \pi \left[\langle M^2(0) \rangle - 2\, D \, \langle \tau^* \rangle \right]$

$\Longrightarrow$ Need only to know the statistics of $M(0)$ and τ^* for the 1-d component process $x(\tau)$

[Randon-Furling, S.M., Comtet, PRL, 103, 140602 (2009)]

Distribution of M and τ^* for a single Brownian Path



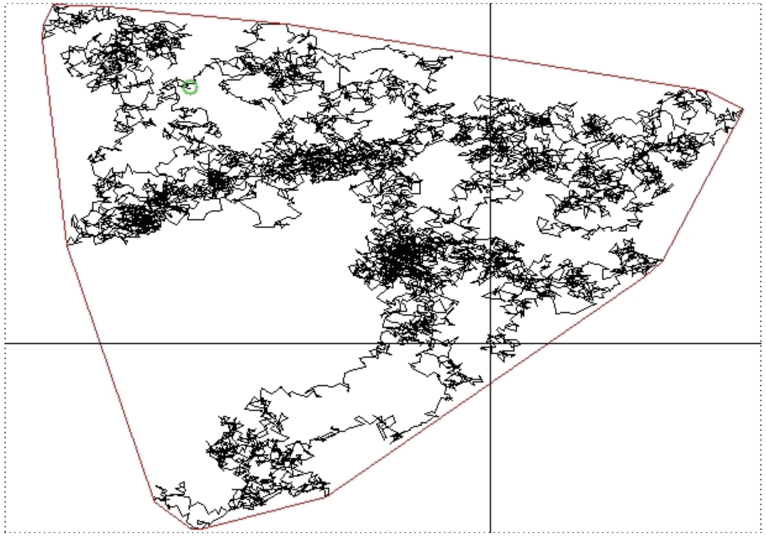
Joint Distribution: $P_1(M,\tau^*|T) = \frac{M}{\pi \tau^{*3/2}\sqrt{T-\tau^*}}\, e^{-M^2/2\tau^*}$ $(D = 1/2)$

$\Longrightarrow$ $\langle M \rangle = \sqrt{2T/\pi}$

$\langle M^2 \rangle = T$

$\langle \tau^* \rangle = T/2$

Results for $n = 1$ Open Brownian Path



$x(\tau)$, $y(\tau)$ $\rightarrow$ a pair of independent one-dimensional Brownian motions over $0 \leq \tau \leq T$

Mean Perimeter

$$\langle L \rangle = \sqrt{8\pi T}$$

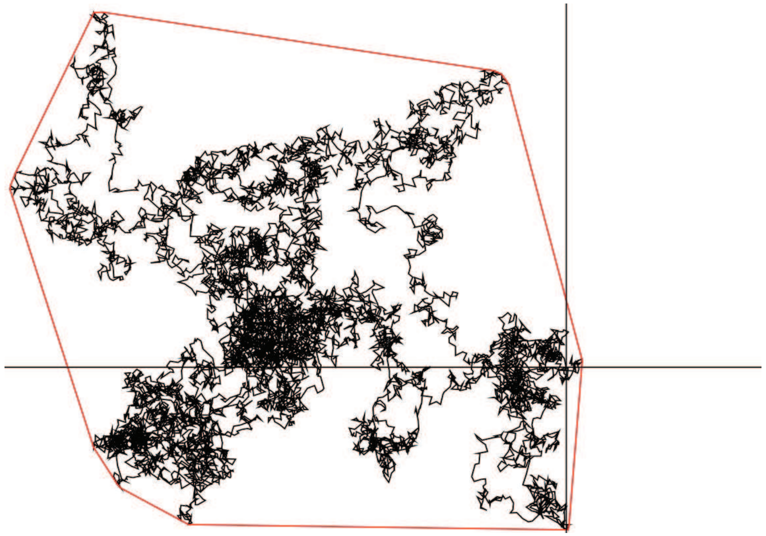
Mean Area

$$\langle A \rangle = \frac{\pi T}{2}$$

Takács, *Expected perimeter length*, Amer. Math. Month., **87** (1980)

El Bachir, (1983)

Results for $n = 1$ Closed Brownian Path



$x(\tau)$, $y(\tau)$ $\rightarrow$ a pair of independent one-dimensional Brownian bridges over $0 \leq \tau \leq T$

Mean Perimeter

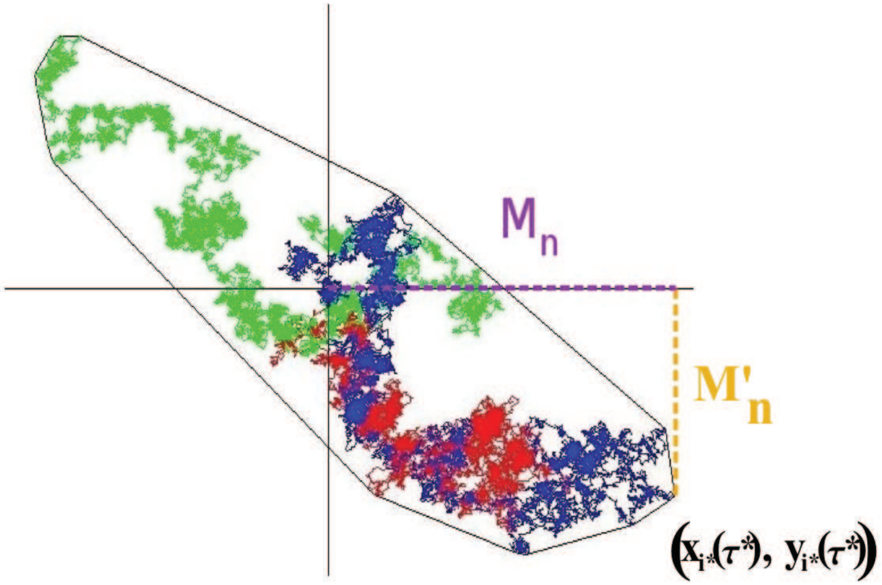
$$\langle L \rangle = \sqrt{\frac{\pi^3 T}{2}}$$ Goldman, '96

Mean Area

$$\langle A \rangle = \frac{\pi T}{3}$$ $\rightarrow$ New Result

[Randon-Furling, S.M., Comtet, PRL, 103, 140602 (2009)]

Convex Hull of n Independent Brownian Paths



$x_i(\tau)$, $y_i(\tau)$ $\to$ $2\,n$ independent one-dimensional Brownian paths each of duration T

Mean Perimeter

$\langle L_n \rangle = 2\pi \langle M_n \rangle$

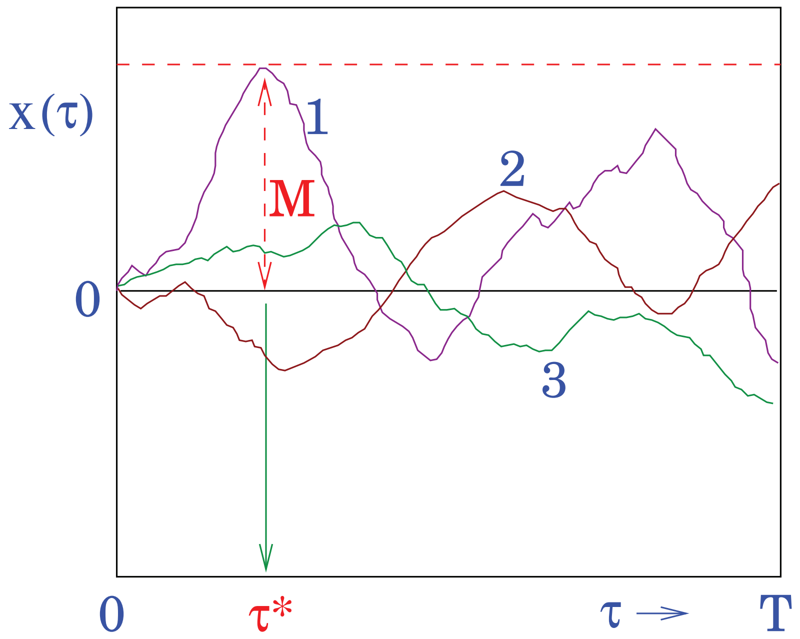
with $M_n = \max_{\tau,i}\{x_i(\tau)\} \equiv x_{i^*}(\tau^*)$

Mean Area

$\langle A_n \rangle = \pi \left[\langle M_n^2 \rangle - \langle [M_n']^2 \rangle \right]$

with $M_n' = y_{i^*}(\tau^*)$

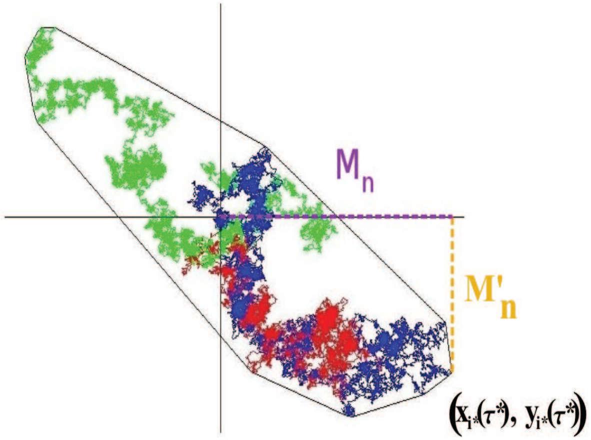
Distribution of the global maximum M and τ^* for n paths



Joint Distribution: $P_n(M, \tau^* | T) = n\, P_1(M, \tau^* | T) \left[\mathrm{erf}\left(\frac{M}{\sqrt{2T}} \right) \right]^{n-1}$

$$\mathrm{erf}(z) = \frac{2}{\sqrt{\pi}} \int_0^z du\; e^{-u^2}$$

Results for n Open Brownian Paths



$x_i(\tau)$, $y_i(\tau) \to 2\,n$ independent one-dimensional Brownian paths over $0 \le \tau \le T$

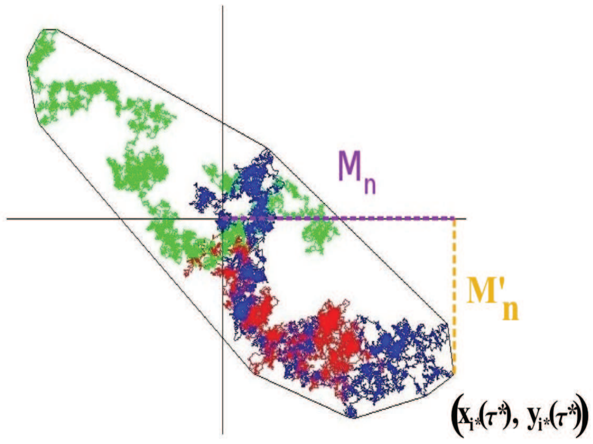
Mean Perimeter (open paths)

$$\langle L_n \rangle = 2\pi \langle M_n \rangle$$

with $M_n = \max_{\tau,i}\{x_i(\tau)\} \equiv x_{i^*}(\tau^*)$

[Randon-Furling, S.M., Comtet, PRL, 103, 140602 (2009)]

Results for n Open Brownian Paths



$x_i(\tau)$, $y_i(\tau) \to 2\,n$ independent one-dimensional Brownian paths over $0 \le \tau \le T$

Mean Perimeter (open paths)

$\langle L_n \rangle = \alpha_n \sqrt{T}$

$$\alpha_n = 4n\sqrt{2\pi} \int_0^\infty du\; u\; e^{-u^2}\, [\mathrm{erf}(u)]^{n-1}$$

[Randon-Furling, S.M., Comtet, PRL, 103, 140602 (2009)]

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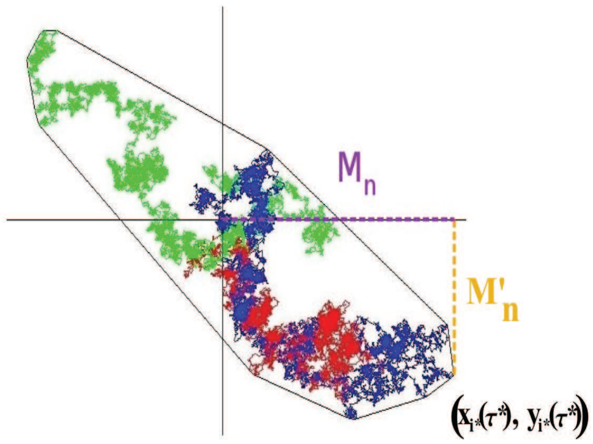

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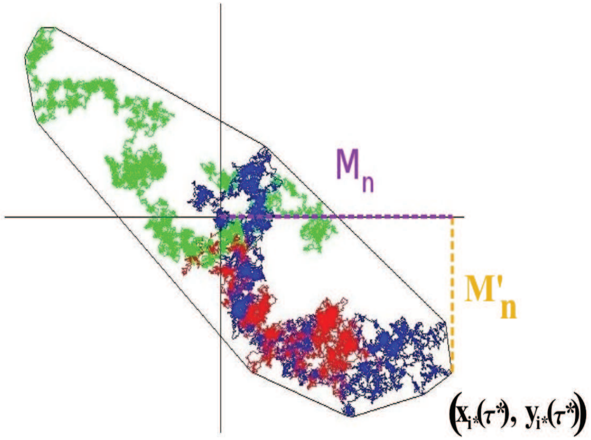
$$\alpha_1 = \sqrt{8\pi} = 5,013..$$

$$\alpha_2 = 4\sqrt{\pi} = 7,089..$$

$$\alpha_3 = 24\, \frac{\tan^{-1}\left(1/\sqrt{2}\right)}{\sqrt{\pi}} = 8,333..$$

[Randon-Furling, S.M., Comtet, PRL, 103, 140602 (2009)]

Results for n Open Brownian Paths



$x_i(\tau)$, $y_i(\tau) \to 2\,n$ independent one-dimensional Brownian paths over $0 \le \tau \le T$

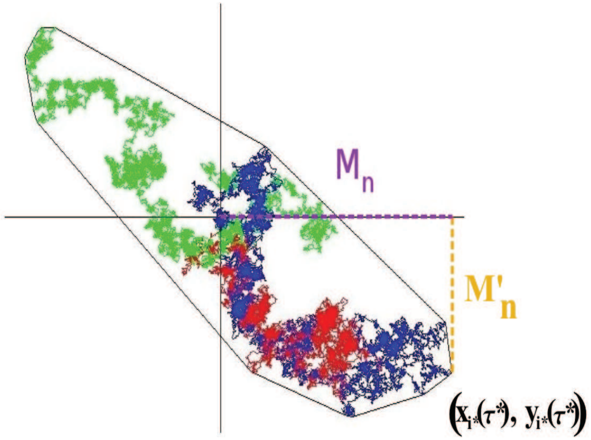
Mean Area (open paths)

$$\langle A_n \rangle = \pi \left[\langle M_n^2 \rangle - \langle [M'_n]^2 \rangle \right]$$

with $M'_n = y_{i^*}(\tau^*)$

[Randon-Furling, S.M., Comtet, PRL, 103, 140602 (2009)]

Results for n Open Brownian Paths



$x_i(\tau)$, $y_i(\tau) \to 2\,n$ independent one-dimensional Brownian paths over $0 \leq \tau \leq T$

Mean Area (open paths)

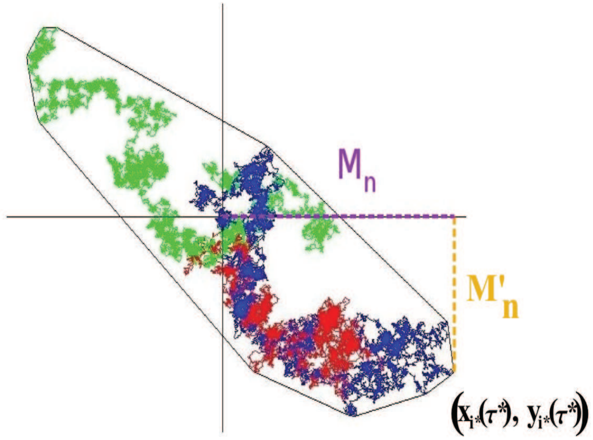
$\langle A_n \rangle = \beta_n T$

$$\beta_n = 4n\sqrt{\pi}\int_0^\infty du\ u\ [\mathrm{erf}(u)]^{n-1}\left(ue^{-u^2} - h(u)\right)$$

$$h(u) = \frac{1}{2\sqrt{\pi}}\int_0^1 \frac{e^{-u^2/t}\ dt}{\sqrt{t(1-t)}}$$

[Randon-Furling, S.M., Comtet, PRL, 103, 140602 (2009)]

Results for n Open Brownian Paths



$x_i(\tau)$, $y_i(\tau) \to 2\,n$
independent
one-dimensional Brownian
paths over $0 \leq \tau \leq T$

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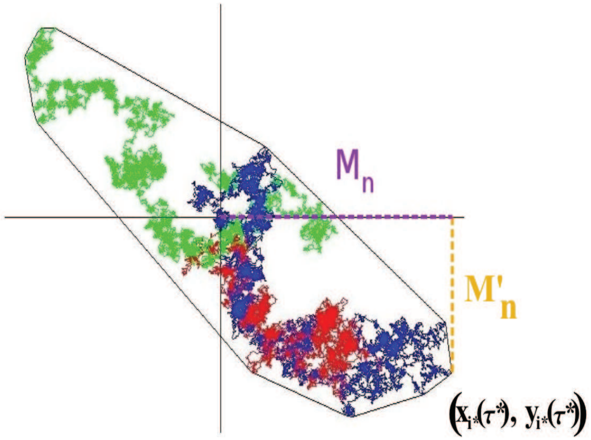
$$h(u) = \frac{1}{2\sqrt{\pi}}\int_0^1 \frac{e^{-u^2/t}\ dt}{\sqrt{t(1-t)}}$$

$$\beta_1 = \frac{\pi}{2} = 1,570..$$
$$\beta_2 = \pi = 3,141..$$
$$\beta_3 = \pi + 3 - \sqrt{3} = 4,409..$$

[Randon-Furling, S.M., Comtet, PRL, 103, 140602 (2009)]

Results for n Closed Brownian Paths



$x_i(\tau)$, $y_i(\tau) \to 2\,n$ independent one-dimensional Brownian bridges over $0 \le \tau \le T$

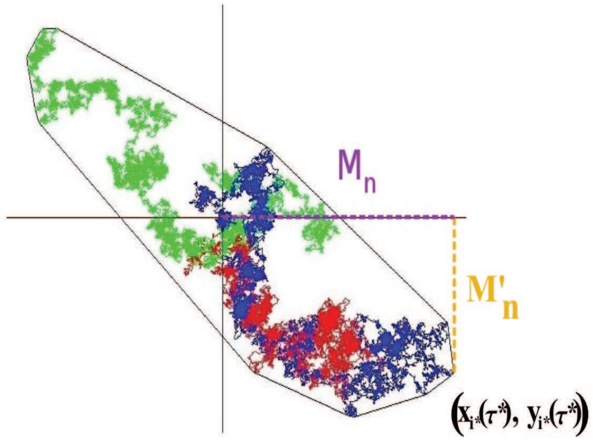
Mean Perimeter (Closed Paths)

$\langle L_n^c \rangle = \alpha_n^c \sqrt{T}$

$$\alpha_n^c = \frac{\pi^{3/2}}{\sqrt{2}} \sum_{k=1}^{n} \binom{n}{k} \frac{(-1)^{k+1}}{\sqrt{k}}$$

[Randon-Furling, S.M., Comtet, PRL, 103, 140602 (2009)]

Results for n Closed Brownian Paths



$x_i(\tau)$, $y_i(\tau) \to 2\,n$
independent
one-dimensional Brownian
bridges over $0 \le \tau \le T$

Mean Perimeter (Closed Paths)

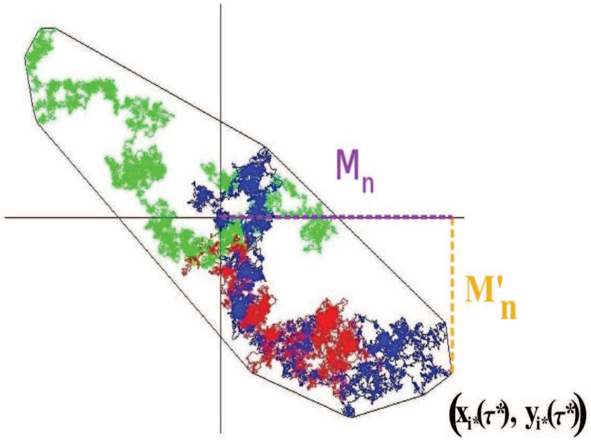
$\langle L_n^c \rangle = \alpha_n^c \sqrt{T}$

$$\alpha_n^c = \frac{\pi^{3/2}}{\sqrt{2}} \sum_{k=1}^{n} \binom{n}{k} \frac{(-1)^{k+1}}{\sqrt{k}}$$

$$\begin{aligned}
\alpha_1^c &= \sqrt{\pi^3/2} = 3,937. \\
\alpha_2^c &= \sqrt{\pi^3}(\sqrt{2} - 1/2) = 5,090.. \\
\alpha_3^c &= \sqrt{\pi^3}\left(\frac{3}{\sqrt{2}} - \frac{3}{2} + \frac{1}{\sqrt{6}}\right) = 5,732..
\end{aligned}$$

[Randon-Furling, S.M., Comtet, PRL, 103, 140602 (2009)]

Results for n Closed Brownian Paths



$x_i(\tau)$, $y_i(\tau) \to 2\,n$ independent one-dimensional Brownian bridges over $0 \le \tau \le T$

Mean Area (Closed Paths)

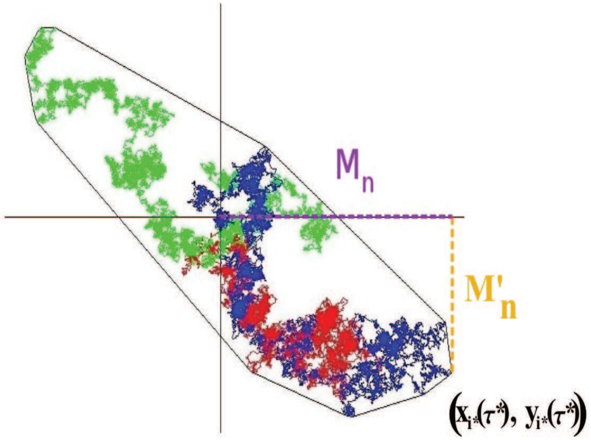
$\langle A_n^c \rangle = \beta_n^c\, T$

$$\beta_n^c = \frac{\pi}{2}\left[\sum_{k=1}^{n}\frac{1}{k} - \frac{n}{3} + \frac{1}{2}\sum_{k=2}^{n}(-1)^k\, w(k)\right]$$

$$w(k) = \binom{n}{k}\,(k-1)^{-3/2}\left(k\tan^{-1}(\sqrt{k-1}) - \sqrt{k-1}\right)$$

[Randon-Furling, S.M., Comtet, PRL, 103, 140602 (2009)]

Results for n Closed Brownian Paths



$x_i(\tau)$, $y_i(\tau) \to 2\,n$ independent one-dimensional Brownian bridges over $0 \le \tau \le T$

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$$w(k) = \binom{n}{k}(k-1)^{-3/2}\left(k\tan^{-1}(\sqrt{k-1}) - \sqrt{k-1}\right)$$

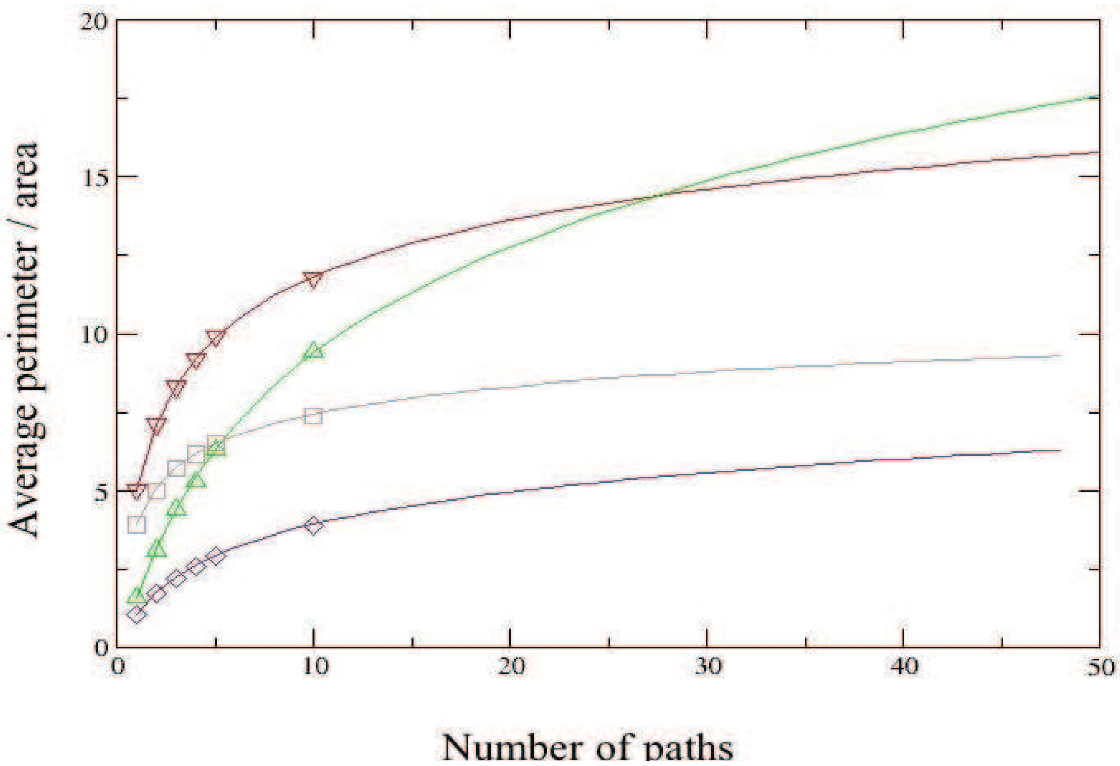
$$\beta_1^c = \frac{\pi}{3} = 1,047..$$

$$\beta_2^c = \frac{\pi(4+3\pi)}{24} = 1,757..$$

$$\beta_3^c = 2,250..$$

[Randon-Furling, S.M., Comtet, PRL, 103, 140602 (2009)]

Numerical Check



The coefficients α_n (mean perimeter) (lower triangle), β_n (mean area) (upper triangle) of n open paths and similarly α_n^c (square) and β_n^c (diamond) for n closed paths, plotted against n. The symbols denote numerical simulations (up to $n = 10$, with 10^3 realisations for each point)

Asymptotics for large n

For n open paths:

$$\langle L_n \rangle \simeq \left(2\,\pi\sqrt{2\ln n}\right)\ \sqrt{T}$$

$$\langle A_n \rangle \simeq (2\,\pi \ln n)\ \ T$$

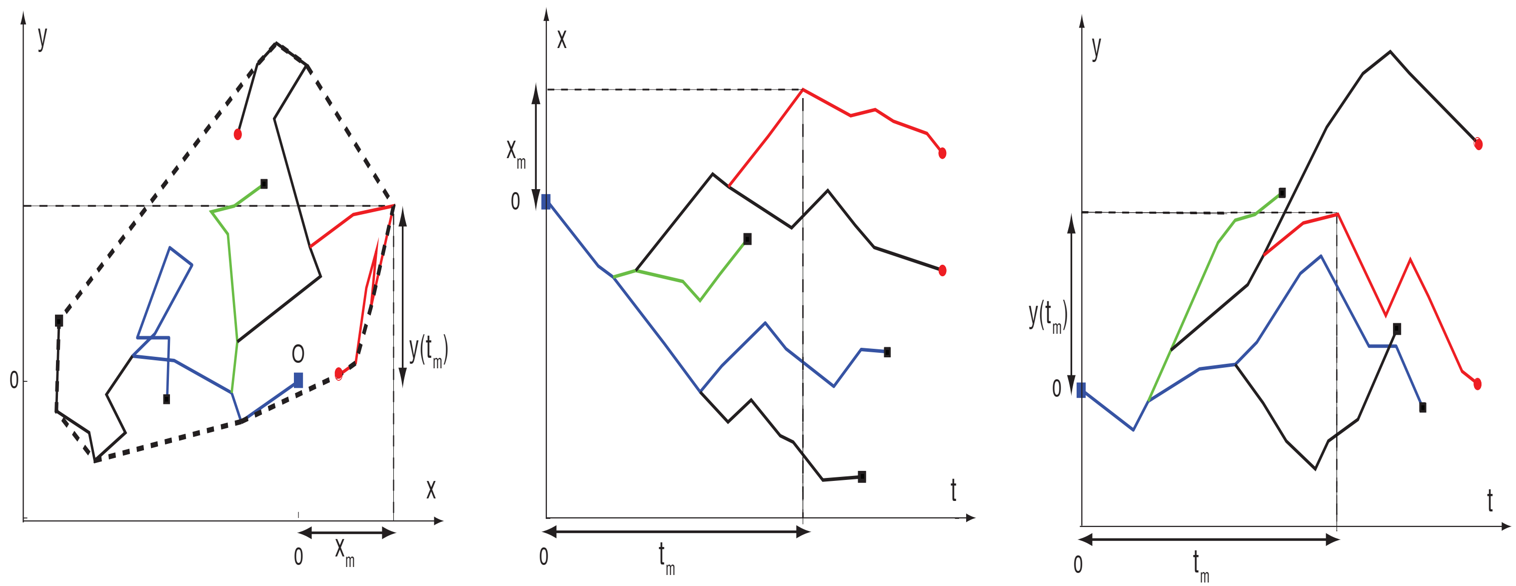
For n closed paths:

$$\langle L_n^c \rangle \simeq \left(\pi\,\sqrt{2\ln n}\right)\ \sqrt{T}$$

$$\langle A_n^c \rangle \simeq \left(\frac{\pi}{2}\ln n\right)\ \ T$$

- As $n \to \infty$, Convex Hull $\to$ Circle (S.M. and O. Zeitouni, unpublished)
- Very slow growth with $n \Longrightarrow$ good news for conservation

Convex hull for animal epidemics: Exact results

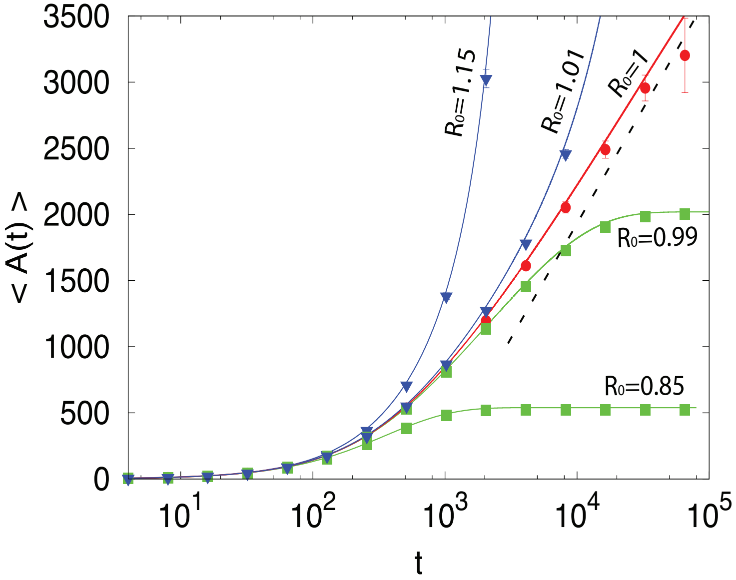


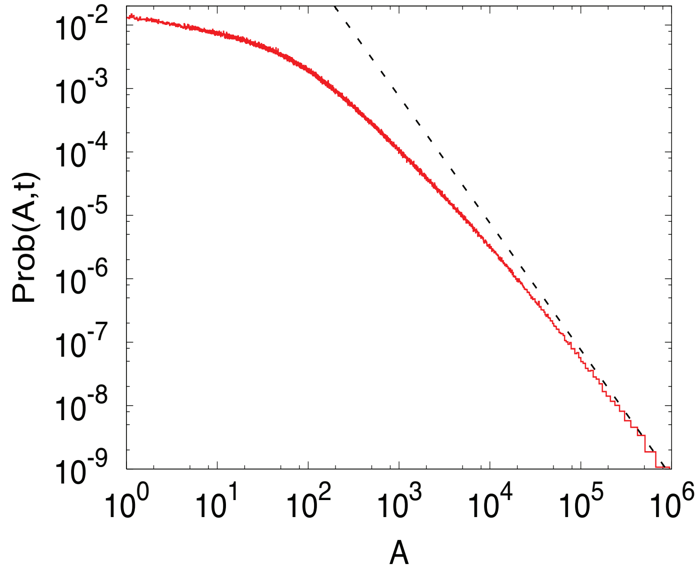
For the critical case $(b = a)$

- mean perimeter: $\langle L(T) \rangle \xrightarrow[T\to\infty]{} 2\pi \sqrt{\frac{6D}{a}} + O\left(T^{-1/2}\right)$
- mean area: $\langle A(T) \rangle \xrightarrow[T\to\infty]{} \frac{24\pi D}{5a} \ln T + O(1)$

[E. Dumonteil, S.M., A. Rosso, A. Zoia, PNAS, 110, 4239-4244 (2013)]

Convex hull for animal epidemics: Exact results





For the critical case ($b = a$)

- distribution of perimeter: $P(L,T) \xrightarrow[T\to\infty]{} P(L) \sim L^{-3}$ for large L
- distribution of area: $P(A,T) \xrightarrow[T\to\infty]{} P(A) \to \frac{24\,\pi\,D}{5\,a} A^{-2}$ for large A

[E. Dumonteil, S.M., A. Rosso, A. Zoia, PNAS, 110, 4239-4244 (2013)]

Summary and Conclusion

- Unified approach adapting Cauchy's formulae

  $\Longrightarrow$ Mean Perimeter and Area of Random Convex Hull

  both for Independent and Correlated points

- Provides a link Random Convex Hull $\Longrightarrow$ Extreme Value Statistics

- Exact results for n planar Brownian paths $\rightarrow$ Open and Closed

  $\Longrightarrow$ Ecological Implication: Home Range Estimate

  Very slow (logarithmic) growth of Home Range with population size n

- Exact results for branching Brownian motion with death

  $\Longrightarrow$ application to the spread of animal epidemics

Open Questions

- Distributions of the perimeter, area of the convex hull of Brownian motion?

- Mean number of vertices on the convex hull of n random walkers in two dimensions

$n = 1 \rightarrow$ Baxter, 1961

$n > 1 \rightarrow$ recent results by J. Randon-Furling, 2013.

- d-dimensions $\rightarrow$ Convex polytopes ?

[recent results for a single Brownian motion in d-dimensions by R. Eldan, arXiv: 1211.2443]

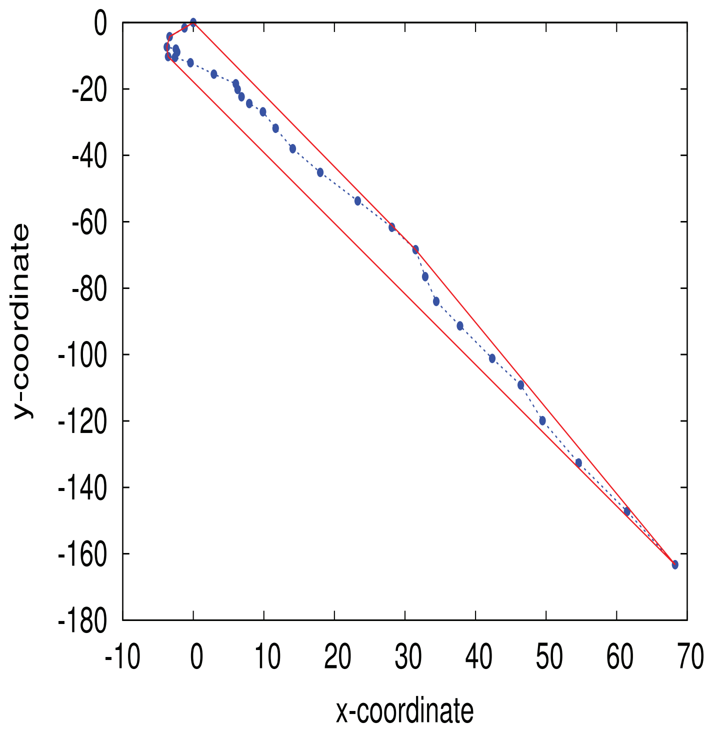
- Effect of Interactions between trajectories on convex hull?

- Non-Brownian paths $\rightarrow$ anomalous diffusion, e.g., Lévy flights, external potential ?

Convex Hull of Random Acceleration Process

- Convex hull of a 2-d random acceleration process: $\boxed{\frac{d^2\vec{r}}{dt^2} = \vec{\eta}(t)}$

  $\vec{\eta}(t) \Longrightarrow$ 2-d Gaussian white noise :$\langle \eta_x(t)\eta_x(t')\rangle = 2\delta(t-t')$
- Let $T \rightarrow$ total duration



- Exact results for the mean perimeter and mean area

mean perimeter:

$$\boxed{\langle L_1 \rangle = \frac{3\pi}{2}\, T^{3/2}}$$

mean area:

$$\boxed{\langle A_1 \rangle = \frac{5\pi}{192}\sqrt{\frac{3}{2}}\, T^3}$$

Reymbaut, S.M. and Rosso, J. Phys. A: Math. Theor. 44, 415001 (2011)

Collaborators and References

Collaborators:

- A. Comtet (LPTMS, Orsay, France)
- E. Dumonteil (CEA Saclay, France)
- J. Randon-Furling (Univ. Paris-1, France)
- A. Reymbaut (Master student at Orsay, France)
- A. Rosso (LPTMS, Orsay, France)
- A. Zoia (CEA Saclay, France)

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- J. Randon-Furling, S. N. Majumdar, A. Comtet, Phys. Rev. Lett. 103, 140602 (2009)
- S. N. Majumdar, J. Randon-Furling, A. Comtet, J. Stat. Phys. 138, 955 (2010)
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