BH Dynamics in AdS/CFT

- work in progress w/ A. Lawrence, S. Shenker, D. Wenren + A. Maloney (...)
- G. Horowitz, A. Lawrence, E.S '09 inside horizon in AdS/CFT
- Emparan '99

Outline

- Setup
- Moduli space & effect of ~~susy~~ compactification
- Wilson lines, electric fluxes, 'long strings', matrix dynamics, hair
- Fireball candidates & bounds
- More general comments

AMPS `12 Hitchcock `56

The Man Who Knew Too Much (1956)

Top 5000

PG 120 min - Thriller - 1 June 1956 (USA)

Your rating: -/10

7.5

Ratings: **7.5**/10 from 27,108 users

Reviews: 168 user | 58 critic

A family vacationing in Morocco accidentally stumble on to an assassination plot and the conspirators are determined to prevent them from interfering.

Director: Alfred Hitchcock

Writers: John Michael Hayes (screenplay), Charles Bennett (based on a story by), 2 more credits »

Stars: James Stewart, Doris Day, Brenda de Banzie | See full cast and crew

An old problem `34

The Man Who Knew Too Much

Directed by Alfred Hitchcock

AMPS '12 used a thought experiment to make a prediction for theory

Firewall : $M_{\cancel{SUSP}} >> T_{BH}$

in particular $\frac{\text{signal}}{\text{noise}} \sim \frac{M_{FW}}{T_{BH}} >> 1$

To settle this we need to control BH dynamics (e.g. in AdS/CFT) well enough to detect this signal

A relatively simple case where the dual QFT has a protected probe of the fate of the BH interior is

Emparan '99 Horowitz Lawrence ES '09

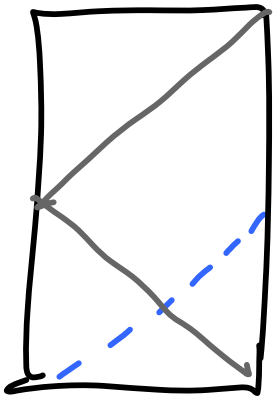
classical metric

$$ds^2\Big|_{\mu=0} = \frac{r^2}{R^2}\left(-d\tau^2 + \tau^2 d\sigma^2\right) + \frac{R^2}{r^2}dr^2 + R^2 d\Omega^2$$

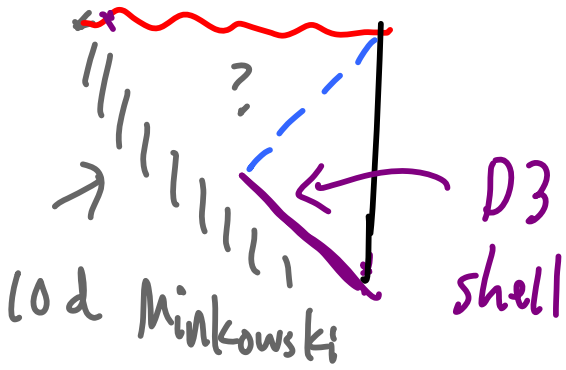
$\sigma \sim \sigma + 1$

$\mathbb{H}_3/\Gamma$

Classically this is an orbifold of a patch of the Poincare patch, freely acting except at $\tau = 0$ singularity



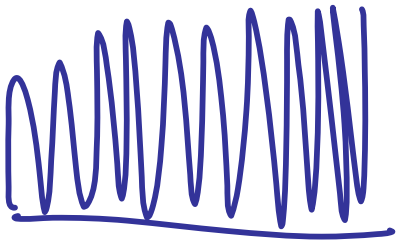
form naturally:



Dual QFT : $\mathcal{N}=4$ $U(N_c)$ SYM

on $-dt^2 + r^2 d\Omega^2$

Before compactifying, QFT on $\mathbb{H}_3$



Dual QFT : $N=4$ SYM on

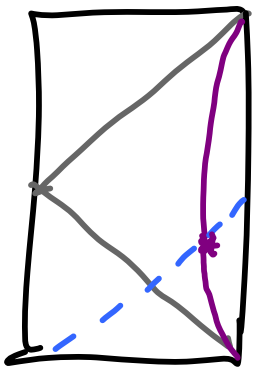
$$-dt^2 + t^2 d\sigma^2$$

$d\sigma^2$ ← $\mathbb{H}_3/\Gamma$

Compact ⇒

- Classical moduli space $\supset (\mathbb{R}^6 \times T^{b_1})^N / S_N$
  actually $\exists$ N^2-dim'l space of flat connections
- Moduli are dynamical QM. variables (below a gap to QFT modes on $\mathbb{H}_3$), not superselection parameters. Part of $N \times N$ matrix
- BH decays via brane nucleation
- ~~SUSY~~ ← $H = \frac{da}{a} = \frac{1}{\eta} = \frac{1}{l_\Sigma}$

Horizon Locus



$$r_h \gamma_h = R^2$$

$$\phi_h = \frac{\sqrt{\lambda}}{\gamma_h}$$

$\Updownarrow$

m_W

under $U(N+1) \to U(N) \times U(1)$

Before compactifying,

$\exists$ exact moduli space with protected (uncorrected) metric

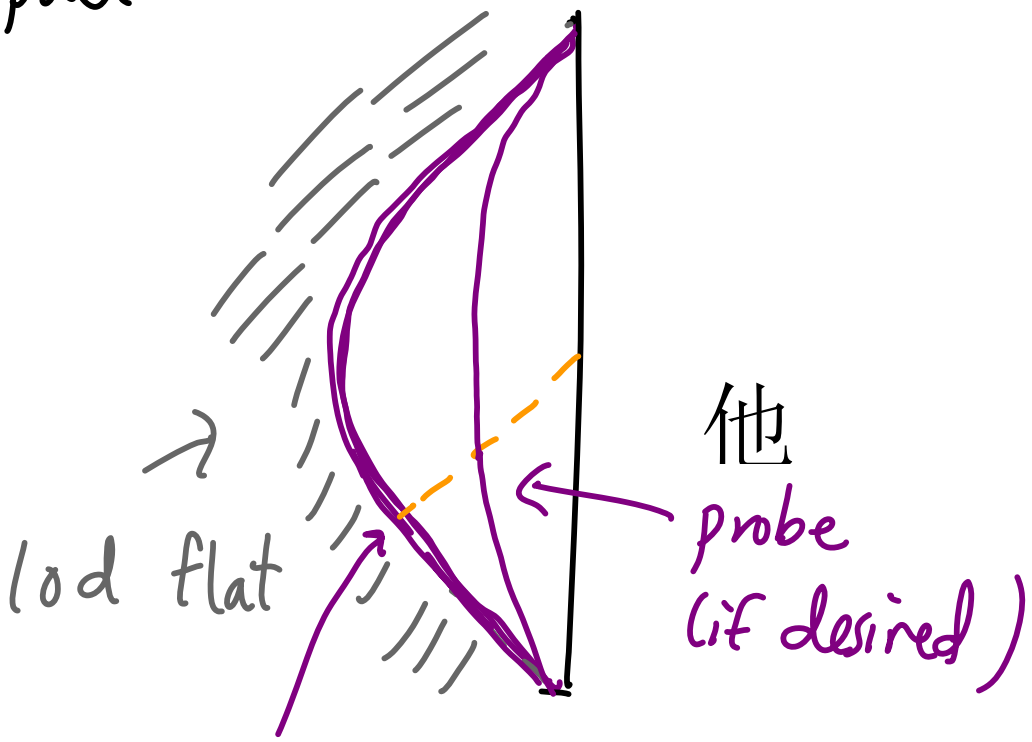
$$S_{U(1)} = \int dt \, \frac{r^3 d^3\sigma \sqrt{\tilde{g}}}{g_s} \left\{ (\partial\phi)^2 + \cdots \right\}$$

$\forall \lambda$

where $\phi = \langle \phi \rangle + \delta\phi$

$\langle \phi \rangle$ Parameter

Noncompact



→ Compactify on

$$\Sigma = \begin{cases} \cdot\ T^3_{susy} \text{ periodic b.c.} \\ \cdot\ T^3_{susy} \text{ anti-periodic (Scherk-Schwarz)} \end{cases} \Big\} \text{QFT + GR side}$$

$$\cdot\ \text{our } \mathbb{H}_3/\Gamma \Big\} \text{QFT side}$$

→ ϕ dynamical and interacts w/ whole matrix, but initially very heavy & weakly coupled

$$\mathcal{L}_{U(1)} = \frac{Vol}{g_s} \cdot \frac{\dot{\phi}^2}{2} + \dots = \frac{1}{2} m v^2$$

uncertainty $\Delta\phi\,\Delta\dot{\phi} \gtrsim \frac{g_{YM}^2}{Vol}$

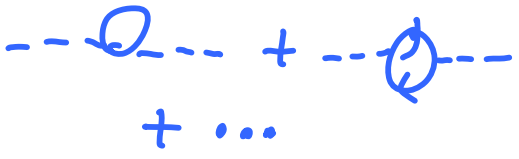
Minimal uncertainty wavepacket

$$\Delta\phi \sim \frac{g_{YM}}{l_\Sigma} = \frac{g_{YM}}{|\gamma|} << \frac{\sqrt{\lambda}}{\gamma}$$

$$\boxed{\Delta\phi << \phi_{horizon}}$$

T^3_{susy} : v^2 term protected

$T^3_{\cancel{susy}} + |H_3/\gamma$: ~~susy~~ injected at scale $\frac{1}{l_\Sigma} = \frac{1}{|\gamma|} << M_W, M_{FW}$

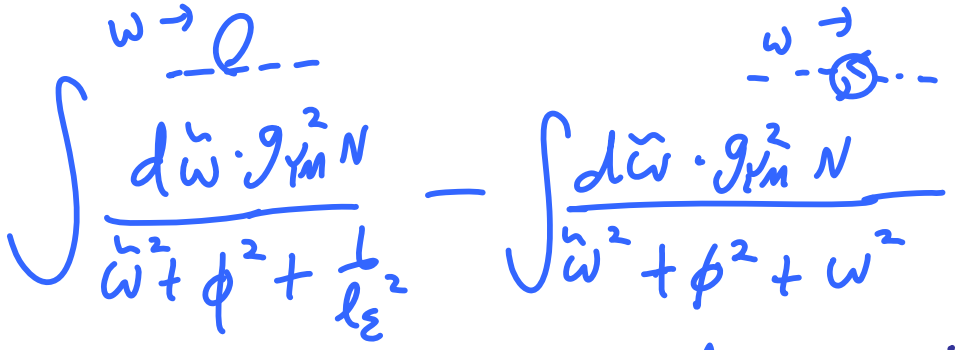
~~SUSY~~ in W loops 

Ψ_{initial} peaked at $\begin{pmatrix} \phi_{11} & 0 \cdots 0 \\ 0 & \\ \vdots & \Phi_{N-1 \times N-1} \\ 0 & \end{pmatrix}$

v^0, v^2 terms cancel

in SUSY case to all orders,

residual ~~SUSY~~ $\propto \frac{\lambda^n}{(l_\varepsilon \phi)^{3n}} \ll 1$ at horizon



$$\int \frac{d\tilde{\omega} \cdot g_{YM}^2 N}{\tilde{\omega}^2 + \phi^2 + \frac{1}{l_\varepsilon^2}} - \int \frac{d\tilde{\omega} \cdot g_{YM}^2 N}{\tilde{\omega}^2 + \phi^2 + \omega^2}$$

$$\rightarrow \quad \phi^2 \times \frac{\lambda}{l_\varepsilon^2} \int \frac{d\tilde{\omega}}{(\tilde{\omega}^2 + \phi^2)^2} \sim \frac{\lambda}{l_\varepsilon^2 \phi}$$ marginal at horizon

Matrix dynamics

- Where & when does the probe dissolve into the YM matrix? $\phi_* \overset{?}{\gtrsim} \phi_h$

Usual matrix Q.M. : dim'l analysis

$\Rightarrow$ powers of $\frac{\lambda_{QM}^{\frac{1}{3}}}{\phi}$ where $\lambda_{QM} = \frac{\lambda}{l_s^3}$

(std in D0-brane matrix theory BFSS Joe P '99)

suggests $\phi_* \, l_s \sim \lambda^{\frac{1}{3}} \ll \sqrt{\lambda}$ ← horizon

is where perturbation theory breaks down

- Full problem $\cong$

$$\int \dot{U}^2 + \mathrm{Tr}\left(U^\dagger \dot{U}\right)^2 + \cdots$$

↑ holonomies, N^2 classically

Ititzykson/Zuber ...

Compactification → Topological sectors

In Scherk-Schwarz a $\mathbb{H}_3/\Gamma$,
the system has a new
instability to condense
electric flux loops:

$$\langle W_k = P e^{i\oint d\sigma A^0(\sigma,\sigma_1,\gamma)} \rangle$$

In T^3_{susy} case, this is dual
to winding string tachyon condensation

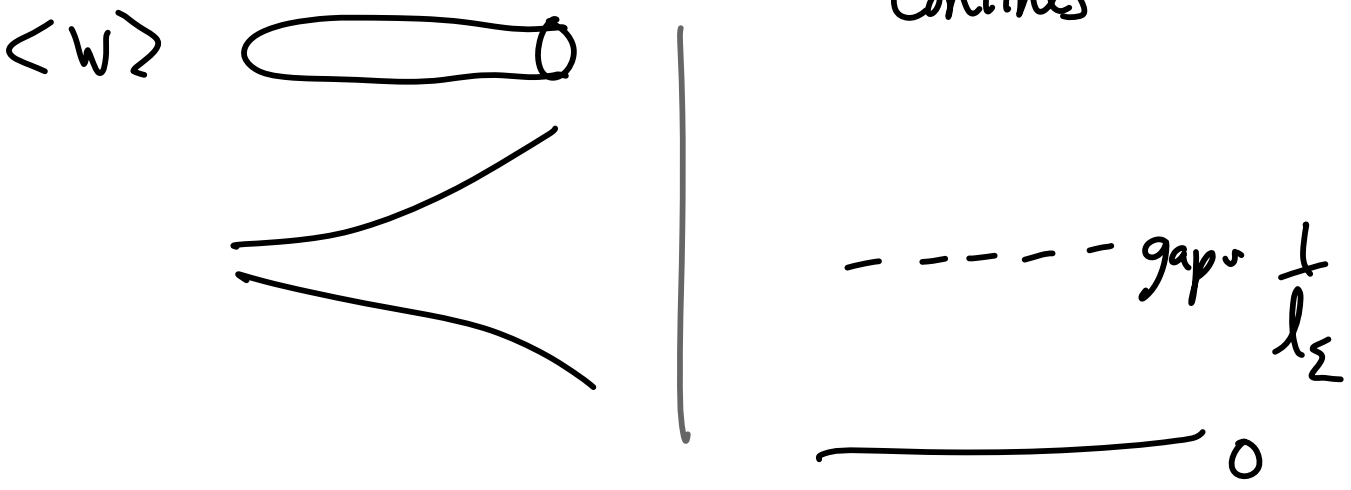
APS, ... Horowitz McGreevy ES ...

$N=4$ SYM $/ S^1$

Scherk-Schwarz

GR $\Rightarrow$ QFT

Confines



$\langle W \rangle \neq 0$

- on $\mathbb{H}_3/\Sigma$, a gap of $\sim \frac{1}{l_\Sigma}$ would correspond to horizon according to UV/IR $\quad \frac{1}{l_\Sigma} = \frac{1}{R}\left(\frac{r}{R}\right) \Rightarrow r l_\Sigma = R^2$

$$m_W^2 = -\underbrace{\text{tension}^2}_{\text{worldsheet Casimir}} + L^2\,\text{tension}^2$$

At weak coupling, explicit gauge theory computation (Gross/Pisarski/Yaffe '81... Polchinski '91) exhibits this effect for electric flux tubes. $A_{\parallel} = \begin{pmatrix} \theta_1 & & 0 \\ & \theta_2 & \\ 0 & & \ddots \\ & & & \theta_N \end{pmatrix}$ gauge choice

Integrate out $A_\perp$, Φ $\Rightarrow$

$$\text{potential} \propto \sum (\theta_a - \theta_b)^2 \left(2\pi - [\theta_a - \theta_b]\right)^2$$

$$m_\theta \sim \lambda_n^{\frac{1}{2}} / l_\Sigma$$

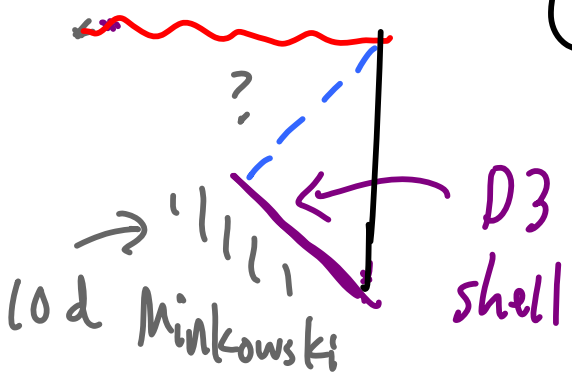
wilson lines driven $\rightarrow$ $\theta_a = \theta_0$

(e.g. can work in static frame)

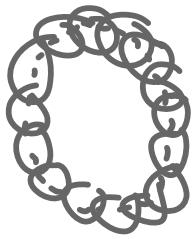
Induces confinement

Consider formation shell around r_f

$(r_f \phi_f = \sqrt{\lambda})$

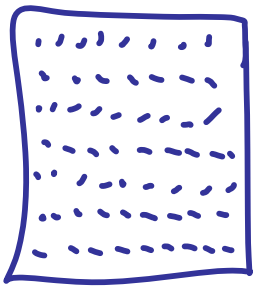


distributed on $\mathbb{R}^6$ → weakly interacting at low energy ⇒



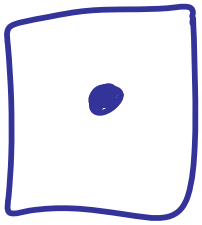
$\theta_a \to \theta_0$

Close enough to extremality, the entropy count favors "long strings" with $(\mathbb{Z}_N)^{b_1}$ Symmetric wilson lines



Maldacena Susskind ... Banks et al
DL-D5 BFSS BH

The potential $\rightarrow \langle W \rangle \neq 0$

$\Rightarrow$ instead 

Is this enough to destroy (or fail to create) the inside?

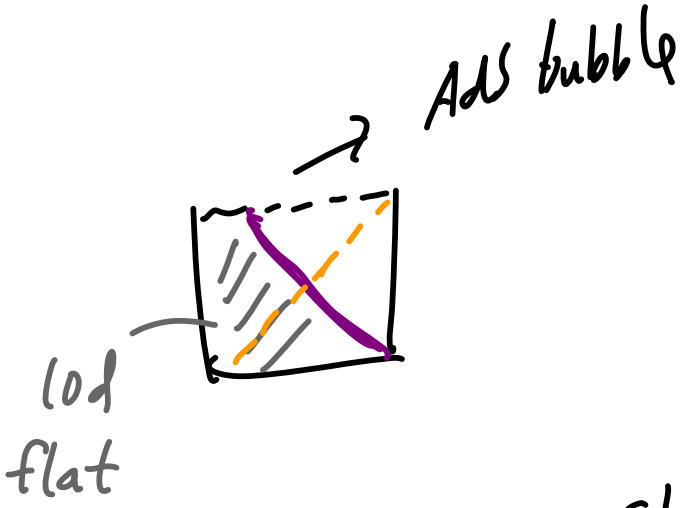
- Initially, the scales are low...

Causality & Confinement

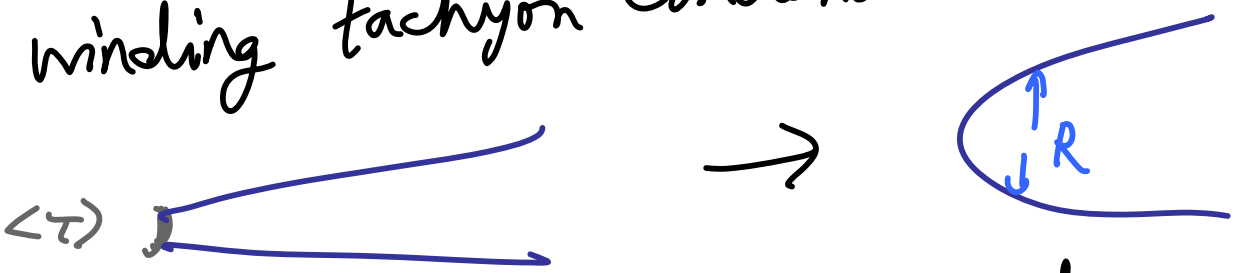
Horowitz / ES

S^1

~~susy~~



The transition proceeds via stringy winding tachyon condensation



timescale bounded by causality

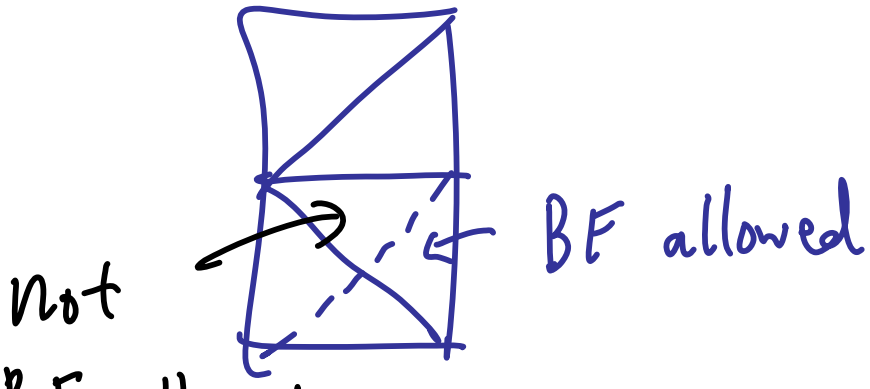
* For compact $(H_3/\Gamma$, QFT bound on spreading stops at l_Σ ...

Another aspect of the compact problem is scalar hair

Read/Santos et al
Maloney et al

$$\begin{cases} \text{inside} & \mu = 0 \\ \text{in + out} & \mu < 0 \end{cases}$$

BF bound
N/A inside
(e.g. after some evaporation)



Not BF allowed

Solutions Bessel ftns, grows exponentially but $\Phi_{hair} \sim \Phi_0 e^{\frac{\Delta r}{R}}$ not large at horizon

↗ Metric + A_μ

So far

- SUSY protects v^2, v^0 against large quantum corrections

  ϕ_{11} joins the matrix further in could → exclusion

- Potential for larger ~~susy~~ via $\langle W \rangle$: Wilson lines clump ≠ long strings

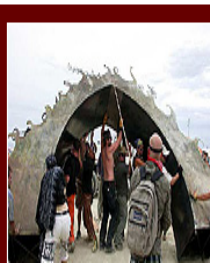
Que Sera Sera ...

General Comments

- S^2 horizon: Ψ breaks SUSY, FW would at a higher scale

- Some cases (Fermi Seasickness) where GR Smooth but branes are (perturbatively) unstable to flying up throat

- Reverse-engineer FW in some case ?



Ten Principles of Burning Man

Burning Man Founder Larry Harvey wrote the Ten Principles in 2004 as guidelines for the newly-formed Regionals Network. They were crafted not as a dictate of how people should be and act, but as a reflection of the community's ethos and culture as it had organically developed since the event's inception.

Radical Inclusion
Anyone may be a part of Burning Man. We welcome and respect the stranger. No prerequisites exist for participation in our community.

Gifting
Burning Man is devoted to acts of gift giving. The value of a gift is unconditional. Gifting does not contemplate a return or an exchange for something of equal value.

Decommodification
In order to preserve the spirit of gifting, our community seeks to create social environments that are unmediated by commercial sponsorships, transactions, or advertising. We stand ready to protect our culture from such exploitation. We resist the substitution of consumption for participatory experience.

Radical Self-reliance
Burning Man encourages the individual to discover, exercise and rely on his or her inner resources.

Radical Self-expression
Radical self-expression arises from the unique gifts of the individual. No one other than the individual or a collaborating group can determine its content. It is offered as a gift to others. In this spirit, the giver should respect the rights and liberties of the recipient.

Communal Effort
Our community values creative cooperation and collaboration. We strive to produce, promote and protect social networks, public spaces, works of art, and methods of communication that support such interaction.

Civic Responsibility
We value civil society. Community members who organize events should assume responsibility for public welfare and endeavor to communicate civic responsibilities to participants. They must also assume responsibility for conducting events in accordance with local, state and federal laws.

Leaving No Trace
Our community respects the environment. We are committed to leaving no physical trace of our activities wherever we gather. We clean up after ourselves and endeavor, whenever possible, to leave such places in a better state than when we found them.

Participation
Our community is committed to a radically participatory ethic. We believe that transformative change, whether in the individual or in society, can occur only through the medium of deeply personal participation. We achieve being through doing. Everyone is invited to work. Everyone is invited to play. We make the world real through actions that open the heart.

Immediacy
Immediate experience is, in many ways, the most important touchstone of value in our culture. We seek to overcome barriers that stand between us and a recognition of our inner selves, the reality of those around us, participation in society, and contact with a natural world exceeding human powers. No idea can substitute for this experience.