



WHAT IS...

# Symplectic Geometry

Tara S. Holm

Communicated by Cesar E. Silva

*Symplectic structures are floppier than holomorphic functions or metrics.*

In Euclidean geometry in a vector space over  $\mathbb{R}$ , lengths and angles are the fundamental measurements, and objects are rigid. In symplectic geometry, a two-dimensional area measurement is the key ingredient, and the complex numbers are the natural scalars. It turns out that sym-

plectic structures are much floppier than holomorphic functions in complex geometry or metrics in Riemannian geometry.

The word “symplectic” is a calque introduced by Hermann Weyl in his textbook on the classical groups. That is, it is a root-by-root translation of the word “complex” from the Latin roots

*com* – *plere*,

meaning “together – braided,” into the Greek roots with the same meaning,

–  $\delta$ .

Weyl suggested this word to describe the Lie group that preserves a nondegenerate skew-symmetric bilinear form. Prior to this, that Lie group was called the “line complex group” or the “Abelian linear group” (after Abel, who studied the group).

A differential 2-form on (real) manifold is a gadget that at any point  $\in$  eats two tangent vectors and spits out a real number in a skew-symmetric, bilinear way. That is, it gives a family of skew-symmetric bilinear functions

$$+ \quad = \quad \rightarrow \mathbb{R}$$

Tara S. Holm is professor of mathematics at Cornell University and Notices contributor. She is grateful for the support of the SI-mans Foundation. Her e-mail address is [toh@math.cornell.edu](mailto:toh@math.cornell.edu).

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depending smoothly on the point  $\in$ . A 2-form  $\in \Omega^2(\ )$  is symplectic if it is both closed (its exterior derivative satisfies  $= 0$ ) and nondegenerate (each function is nondegenerate). Nondegeneracy is equivalent to the statement that for each nonzero tangent vector  $\in$ , there is a symplectic buddy: a vector  $\in$  so that  $(\ , ) = 1$ . A symplectic manifold is a (real) manifold equipped with a symplectic form.

Nondegeneracy has important consequences. Purely in terms of linear algebra, at any point  $\in$  we may choose a basis of that is compatible with  $\ ,$  using a skew-symmetric analogue of the Gram-Schmidt procedure. We start by choosing any nonzero vector  $\uparrow$  and then finding a symplectic buddy  $\downarrow$ . These must be linearly independent by skew-symmetry. We then peel off the two-dimensional subspace that  $\uparrow$  and  $\downarrow$  span and continue recursively, eventually arriving at a basis

$$\downarrow \uparrow \downarrow \uparrow \dots$$

which contains an even number of basis vectors. So symplectic manifolds are even-dimensional. This also allows us to think of each tangent space as a complex vector space where each  $\downarrow$  and  $\uparrow$  span a complex coordinate subspace. Moreover, the top wedge power,  $\in \Omega^{2n}(\ )$ , is nowhere-vanishing, since at each tangent space,

$$(\downarrow \uparrow \downarrow \uparrow \dots) \neq 0.$$

In other words, is a volume form, and is necessarily orientable.

Symplectic geometry enjoys connections to algebraic combinatorics, algebraic geometry, dynamics, mathematical physics, and representation theory. The key examples underlying these connections include:

- (1)  $= \mathbb{C}^2 = \mathbb{C} \times \mathbb{C}$  with  $(\ , ) =$  signed area of the parallelogram spanned by and;
- (2) any Riemann surface as in Figure 1 with the area for  $\uparrow$  and  $\downarrow$  in (1).



Figure 1. The area form on a Riemannian surface defines its symplectic geometry.

# Symplectic Geometry

**Thomas Griffiths**



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