DNA origami relies on the folding of a long single-stranded DNA, or scaffold, into a pre-designed shape using hundreds of smaller single DNA strands, called staples. Each staple has multiple binding sites able to bring together more distant parts of the scaffold strand via crossover base pairing. A typical planar DNA origami might contain up to 200 staple strands. The planar structures can be assembled into more complex 3D structures. One-pot self-assembly is used to construct DNA origami, where an excess of staples is added into a reaction mixture with the scaffold. DNA origami structures are computationally designed with the help of design software. Predicting the folding of the designed DNA structures is done using molecular dynamics simulations to rapidly screen for the desired assembly. When assembling the origami structures, it is important to optimize magnesium concentration and the number of staple strands compared with scaffold strands.

Reproducibility and data deposition

Ensuring reproducibility in DNA origami experiments requires several key aspects. Optimization of annealing and assembly processes can reduce by-products such as dimers, trimers and other aggregates. The DNA purification method should be selected based on yield and duration, as well as volume limitation, dilution, residuals and damage. Storage temperature and cationic strength are crucial for stabilization and storage of DNA origami structures. Sufficient general information and detailed experimental conditions and procedures must be reported. General information includes design, assembly and purification processes, as well as the details of quality analysis approaches. The scaffold DNA sequences should be deposited in a public repository like GenBank, and custom software should be made freely available in a public repository.

Results

Characterization of purified DNA origami structures is needed to determine the quality, yield and correctness of the assembly.

Applications

DNA origami structures represent a versatile platform for a number of applications, from materials science to physics and biology. DNA origami structures have been used as templates for assembling diverse materials with nanometre precision. They can be used as anchors to attach other nanomaterials, which has been done for colloids, metals and semiconductor particles. DNA origami structures are also useful as masks for nanolithography. Enzyme catalysis is facilitated by conjugating proteins to DNA nanostructures to place them in proximity in 1D, 2D or 3D space. Because DNA is an information-carrying molecule, it is an attractive material for computation, and DNA origami-based robots have been designed. DNA origami structures can also be used in drug delivery and to aid in bioimaging.

Limitations and optimizations

The complexity of the available design and simulation tools, many of which require computational knowledge to use, limit the wide adoption of DNA origami techniques. Designing larger structures requires the use of longer scaffolds or stitching together multiple smaller structures, both of which result in a decrease in assembly yield.

Outlook

The development of simple design and simulation tools will help automate the assembly of DNA origami structures and improve our understanding of the origami folding process. Combination of DNA origami structures with other ‘space-filling’ materials will enable the construction of larger structures. As the field moves forwards, researchers will spend less time refining the technique itself and will instead focus on the specifics of the application of DNA origami across disciplines.