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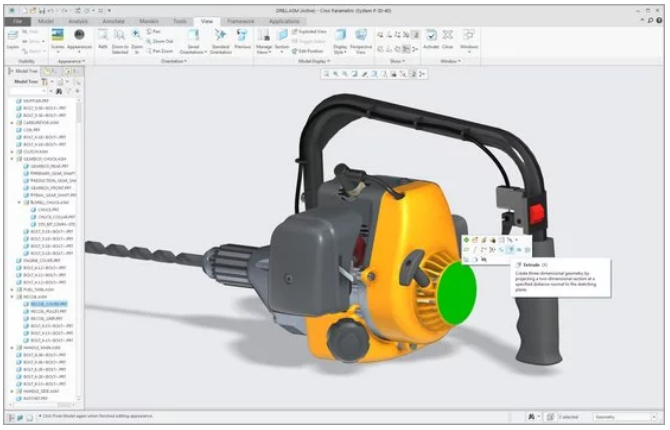


Creo Parametric is the successor to Pro/ENGINEER, which introduced the CAD industry to history-based parametric design.(Image courtesy of PTC).

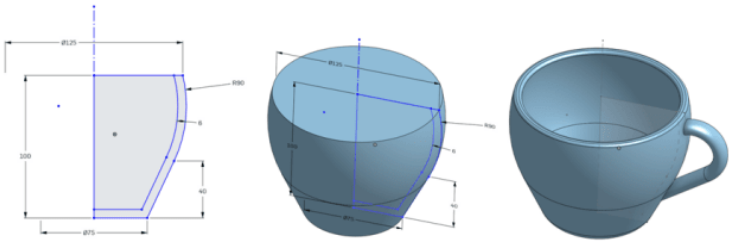
A key milestone in the history of computer-aided design (CAD) came with the 1987 release of Pro/ENGINEER, now PTC Creo, which introduced the CAD industry to history-based parametric modeling. Since then, the parametric paradigm has been employed in almost every mainstream CAD program, including SOLIDWORKS, Autodesk Inventor, Creo Parametric, CATIA, NX, and Onshape. If you've done any CAD modeling in the past two decades, chances are you're familiar with history-based parametric design.

In a nutshell, parametric design involves engineers building up a 3D geometry piece by piece. 2D sketches turn into 3D features, with constraints and relations duly applied to fit the designer's intent. However, since each step follows from preceding steps, parametric design can require careful planning.

Despite the power and popularity of parametric modeling, another CAD paradigm has its own share of proponents: direct modeling. In direct modeling, geometry is king. Users no longer need to worry about the history of their part and can instead act directly on the 3D geometry as is. Some modern CAD systems use direct modeling instead of history-based parametric modeling, while others provide a blend of parametric and direct tools.

To better understand the differences between parametric and direct modeling, what use cases they might be best for, and how they might continue to evolve, we spoke to experienced CAD users and industry insiders for their take on the two paradigms.

Parametric Modeling



Parametric design starts with a sketch (left) and adds features (such as revolve, middle) to build up the final design (right). (Model from Onshape tutorial created by author).

First of all, let's clarify the terminology we're using. The design paradigm pioneered by Pro/ENGINEER is perhaps most properly called "history-based," as it's the linear step-by-step nature of the model that really differentiates it from direct modeling, which might also be called "history-free."

"History-based CAD software relies on the user to build an individual part with a series of features," wrote veteran CAD user Matt Lombard in an eBook (https://www.engineering.com/LinkClick.aspx?link=http%3a%2f%2fwww.siemens.com%2fplm%2flovemycad&tabid=6551&portalid=0&mid=429) about Siemens' CAD software Solid Edge. "The software remembers the features in order, and the model must resolve these features in order perfectly at every step to move forward. You can think of this method of model building like a computer program. You give the computer instructions for every step, and it executes those steps for every time the model must be rebuilt."

Nonetheless, history-based modeling is often referred to as "parametric," and so we'll treat the two terms as similar. Just keep in mind this caveat from Lombard: "People frequently have the mistaken idea that only history-based software is parametric. Parametric means that the model is driven by parameters, which can include dimensions,

pattern instances, wall thicknesses, hole diameters and depths, and so on."

Lombard's analogy of a computer program is an apt one for parametric modeling. Just as when writing a program, the more an engineer thinks ahead about what is trying to be accomplished, the better the end result. Even though a model, like a program, can be put together on the fly, it might be sloppy and difficult for other engineers to edit.

Roland Schwarz, another experienced CAD user, pointed out that this fact of parametric modeling can be a double-edged sword.

"If you work with somebody that's really good at parametrics and structures their project in a good, thought-out, rigorous way, it's fantastic," Schwarz said. "But you can have somebody that just gets in there and chops and changes and has stuff copied in the wrong places, and there's not a logical system to it. That's when it gets messy, and I just want to start from scratch with an export and import." (Exporting and importing the model removes its feature history and turns it into what's called a "dumb geometry," which is just the geometry without design intent).

The best parametric CAD designers are so adept at structuring their projects that they can sometimes be identified just by looking at one of their models, as if they left behind digital fingerprints on the history tree. Even though the end model is exactly the same, there are many ways to get there—and some are definitely better than others.

"And my way's the best," joked Schwarz. "That's what every good CAD modeler will say."

Parametric modeling is extremely useful for products that are driven by dimensions—think standard office fare like desks and shelving or tools that can vary in size. With the parametric approach, engineers can quickly and easily create different configurations of their designs.

But from where the not-so-rigorous modelers live, cracks have started to appear in the parametric modeling paradigm.

"Sometimes I think you can get bogged down in the history," said Bruce Bartlett, another CAD veteran. "As much as the history gives you the ability to change things quickly, the disadvantage is if you don't understand how it's built or you have somebody that's building stuff that gets a bit out of control, you can spend more time wading through the history tree than just grabbing some faces and moving them."

Another weakness of parametric modeling is that as the number of features increases, so does the computation required to update your model.

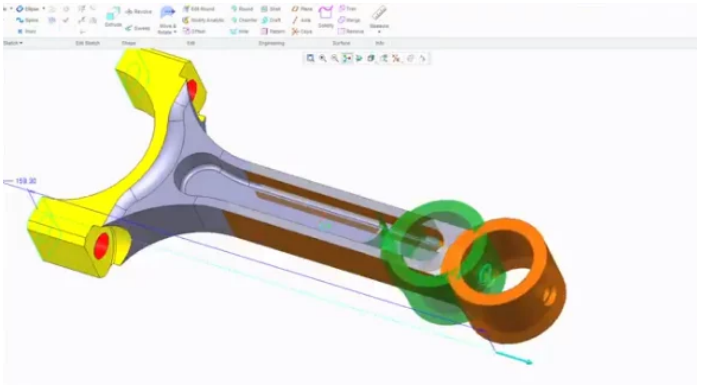
"If you have a part with 1,000 features in the history tree, when you edit the last feature in that tree it goes very quickly," explained Dan Staples, Siemens PLM vice president of mainstream engineering. "But when you edit the first feature in that tree, it might take a very long time because it has to compute all 1,000 in between before it gets to the 1,001st feature."

With its balance of strengths and weaknesses, is parametric modeling the best option out there for CAD design? Staples doesn't think so.

"The notion of editing a dimension to achieve a very predictable result that respects the intent of the designer is inherently valuable," he said. "The implementation known as history-based design, done by Pro/ENGINEER back in 1987 and copied by virtually everyone else now for the last 25 years, is not the most efficient way to edit that dimension."

Staples, naturally enough, advocates Siemens' synchronous technology, a paradigm we'll discuss later.

Direct Modeling



Screenshot of direct modeling in Creo Direct. (Image courtesy of PTC).

As its name indicates, direct modeling offers designers a what-you-see-is-what-you-get approach to building and editing their models.

"There seems to be no end of experts arguing over finely nuanced definitions and variations of this term, but in general, direct edit is a CAD method where you directly manipulate faces of the model, rather than indirectly edit feature definitions or sketches…how the geometry is made really doesn't matter and, frankly, isn't as interesting as how the geometry is changed," Lombard wrote.

In direct modeling, designers can push and pull on their model to change it. One benefit of this capability is the ease with which designs can be altered, enabling rapid iteration and prototyping. For that reason, direct modeling has found a niche in the world of industrial design, where fluid curves and bold aesthetics play a big role.

"There are use cases, such as highly organic design, sculpting, concept design, generative design and de-featuring for analysis, where a totally non-parametric toolset can be an excellent and sometimes the best choice," said Dave Corcoran, Onshape co-founder and vice president of research and development.

Furthermore, without the dependencies and history of parametric modeling, direct modeling can eliminate some of the problems of poor parametric design.

"I think the real test of a CAD modeler isn't what they can make, it's what they can change. Direct modeling definitely opens up the field vastly about what can they change without causing a complete disruption," Schwarz said.

The ability to change a model without worrying about breaking it can mean a lot, especially for companies looking to extend the utility of their CAD model. Schwarz described CAD models as assets, and like any other asset, they require an investment to secure.

"A lot of time and money goes into making a CAD model, and you want to protect those, and you want them to remain useful. Direct modeling will protect that investment," Schwarz explained.

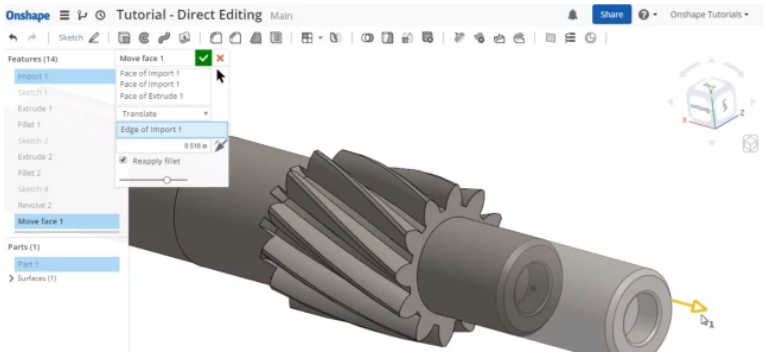
But direct modeling comes with its own share of drawbacks.

"Most history free systems do not deal well with editing of dimensions and getting a predictable result," Staples said. "Sometimes you'll hear people talk about a push-me-pull-you kind of system, and they look very sexy, but when push comes to shove at the end of the day, you really want to be able to edit dimensions and create dimensional places and so on."

Another problem with direct modeling is that, for most CAD modelers, it's simply not what they're used to. After years of experience with parametric design—and years of getting used to its shortcomings—there may just be a lack of motivation to consider an alternative.

"I don't think parametric modeling's going away anytime soon," Schwarz said. "There's a very large population of users out there that are well staked out in it and like it, or at least they're comfortable with it and not going anywhere. I think direct modeling is a huge step forward. At the same time I think there's a culture that's got to evolve around it—where it becomes more accepted and more understood about the best ways to use it—especially in terms of managing a modeling project over the life of a product or even the life of its initial development without having it become a bigger problem than a solution."

Blurring the Line Between Design Paradigms

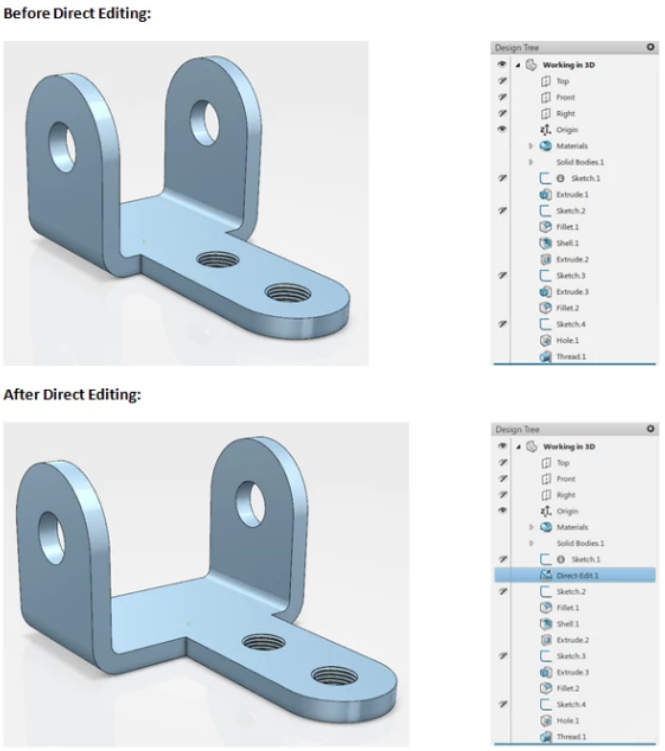


Screenshot of direct editing in Onshape using the Move Face tool. Note how this tool creates a feature in the history tree. (Image courtesy of Onshape).

Most mainstream CAD systems offer some mixture of both parametric and direct tools, although the capability of these tools can vary.

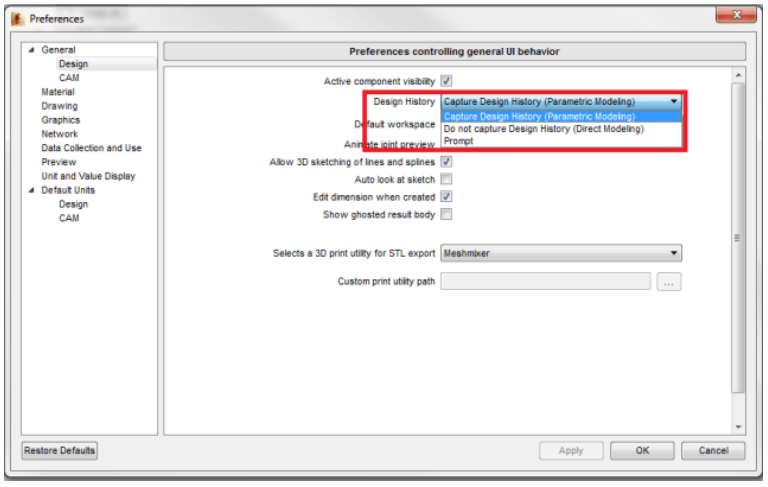
"Onshape's a parametric modeler, but it does have a bit of direct modeling built over the top of it," explained Bruce Bartlett, an Onshape user. "It's direct modeling, but it's still parametric. Sometimes I wish it could be just a pure direct modeler, and we could just move faces around without any history."

What Bartlett is referring to is that even though these tools act like direct editing tools, they still create features in the history tree. Since true direct modeling is history-free, this approach is only quasi-direct. Like Onshape, SOLIDWORKS also offers direct editing tools that can be handy to users for certain tasks, but ultimately leave features in the history tree, maintaining the potential problems of parametric design.



Example of direct editing in SOLIDWORKS. Note that the feature "Extrude 1" (top) has been replaced by a new feature "Direct-Edit 1" (bottom). (Image courtesy of SOLIDWORKS).

Other CAD programs implement the hybrid tools in different ways. Autodesk's Fusion 360, for instance, allows users to operate in either parametric or direct modeling mode. In direct mode, your design history will not be recorded at all. Users can also convert any feature to a direct modeling feature while leaving the rest of the parametric history tree intact.



In Fusion 360, users can switch between Parametric and Direct Modeling mode. (Image courtesy of Autodesk).

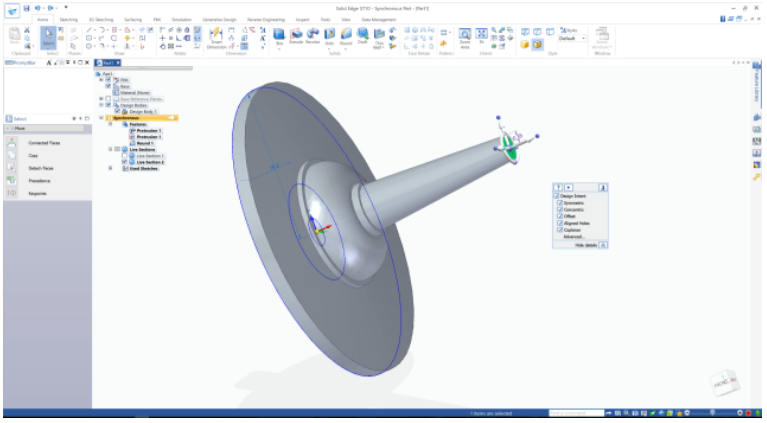
Siemens takes another approach, which it calls synchronous technology, in its NX and Solid Edge CAD software. Synchronous technology claims to uniquely marry the best of parametric and direct modeling capabilities in a single environment.

"With synchronous technology I can either move faces by hand or I can move faces by editing dimensions," Staples explained. "And we've got the unique technology to figure all this out and preserve all that design intent while doing so, but without the baggage of a history tree or any recompute."

Staples believes that synchronous technology goes a step further than the other CAD programs' hybrid blend of tools, sidestepping some problems that can arise in systems that implement direct modeling as a feature in the history tree.

"Think about a simple case, a block with a hole in it. The hole is half an inch in diameter. You've been modeling on this for five years, and it's got 1,000 features, and at the end your boss wants to change that half-inch diameter to 0.4 inches. And you think 'okay, I'm just going to direct edit this,' which adds a 1,001st feature. This is an override that changes the hole to be 0.4 inches.

"It seems like you've solved your problem. But what you've really done is added complexity to the history tree and invalidated the design intent. Now when someone comes back to that part a year later, they're going to go edit that first feature in the tree, and it's going to recompute and get overwritten later in the tree. So this notion that adding more features to the tree is solving some problem… it's solving a very near-term problem but adding many more problems to your engineering process further down the line."



Screenshot of Solid Edge ST10, which offers a blend of parametric and direct modeling called synchronous technology. (Picture courtesy of Siemens).

While some CAD users may have reservations about the claims of synchronous technology, those who use it practically sing its praises. Does this mean the question of parametric vs direct modeling is moot, and synchronous technology is the way forward? That depends who you ask.

"There is no one modeling product approach optimal for all situations. Tools that are over-generalized and try to solve too many use cases in one toolset tend to be hard to use and over-complicated," said Onshape's Dave Corcoran.

Some Solid Edge users have reported difficulties using synchronous technology in certain scenarios, like complex surface modeling, a limitation which Staples admits to. "If you're doing very aesthetically pleasing parts that require a lot of surface based design, synchronous is not well suited to that in its current state," he said.

One might also wonder why if synchronous technology is as beneficial as its proponents claim, it's not a more widespread paradigm. Staples believe the reason is that Siemens is just that far ahead of the technological curve, in large part because of its ownership of the Parasolid kernel and D-Cubed constraint solving SDK. But perhaps there's a simpler reason, which he summarized nicely: "engineers are not people who like to change a lot." History-based parametric modeling is still the dominant paradigm in the CAD world and, despite its drawbacks, it works just fine.

"At this point in history SOLIDWORKS works for 98 percent or better of what anybody's doing out there," Schwarz said.

Over time, however, as new generations of engineers enter the world of CAD modeling, perhaps the old history-based methods will give way to something more like synchronous technology, and the distinction between parametric and direct modeling may no longer be relevant.

"I think over time the line will get blurred, and it will just be different sides of the tool box," Schwarz said.

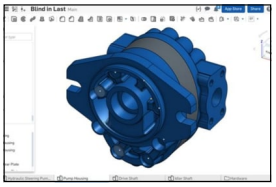
In the meantime, here's a non-exhaustive list of some of the most prominent CAD programs and what design paradigm they adhere to:

Parametric Modeling*	Direct Modeling	Synchronous Technology
• SOLIDWORKS • Onshape • Inventor • Creo Parametric • Fusion 360 • IronCAD • CATIA	• Creo Direct • Creo Elements/Direct Modeling • SpaceClaim • KeyCreator • Rhino	• NX • Solid Edge

*All of these platforms also include some aspects of direct modeling.

Of course, there are many things to consider when choosing a CAD platform, and its design paradigm is but one criterion. Simulation capabilities, CAM, collaboration tools, ease of use, maintenance options, and the extent of its cloud connectivity are a just a few more aspects to evaluate, whatever design paradigm you prefer.

Recommended For You



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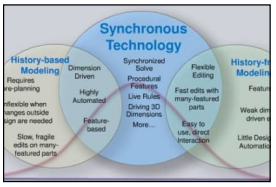
We Just Remade Parametric Modeling, Says Onshape (https://www.engineering.com/DesignSoftware/DesignSoftwareArticles/ArticleID/16560/We-Just-Remade-Parametric-Modeling-Says-Onshape.aspx?e_src=relart)



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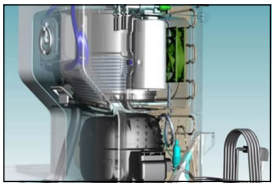

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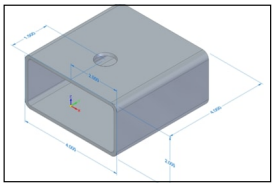

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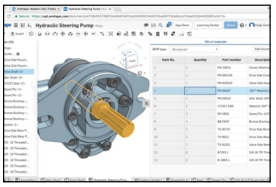

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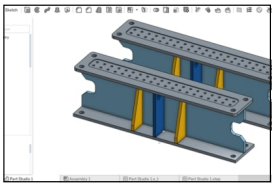

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Kazmier Maslanka • 10 months ago

How much did Siemens pay you to write this article? Almost the entire aerospace industry uses CATIA and you didn't even put it in your list of CAD Software. And you create a chart with a column that uses Siemens proprietary terminology too make it look like they are alone - of course they are alone it is their terminology. And then you justify making a statement based on this "aloneness" and say that Siemens is just that far ahead of the technological curve (because they are alone). You may want to do a fair comparison with NX and CATIA V6.

19 • Reply • Share ›

Michael Alba ➚ Kazmier Maslanka • 10 months ago

The aim of the article wasn't to be a comparison between NX and CATIA--I mentioned NX only because it shares synchronous technology with Solid Edge. Solid Edge (to my knowledge, at least) is unique in its approach to modeling compared to the other CAD programs in its class, which is why I gave it a special mention. And I wasn't making a judgement that Siemens is ahead of the technological curve--that was what Siemens' Dan Staples claimed. You're free to question it, and clearly, you do!

• Reply • Share ›

matt lombard • 10 months ago

Michael,
You got one thing consistently incorrect throughout the article, and allowed others to do the same. Parametric is not the same as history-based. You are comparing parametric with synchronous as if they are different somehow. The difference is that synchronous has no history, not that it has no parameters. Its unfair to label synchronous as non-parametric, because parameters drive changes.

You also quoted someone who equated design intent with feature history. This discounts the role of parametrics in design intent. In combination, these errors imply that synchronous is not capable of design intent. Actually, the design intent in synchronous is far more flexible than any of the other systems, with the ability to change design intent on the fly through selection, and the ingenious

function of how the parameters change on a solid model.

Also, at the end, I think you let the fatalists win, saying that SolidWorks and history-based tools in general have too much momentum to lose now. But you will remember that Pro/ENGINEER at one time seemed unstoppable, until they weren't.

Matt Lombard

1 ▲ ▼ • Reply • Share ›

> **Michael Alba** ➚ matt lombard • 10 months ago
>
> Hi Matt,
>
> Thanks for weighing in. I realize history-based and parametric are not the same thing--I believe I pointed that out near the top of the article, and even included a quote from you to that effect. I didn't mean to imply that synchronous isn't parametric, I was simply trying to distinguish it from your classic Pro/E history-based systems. As you write in your ebook, there's a lot of buzzwords and a lot of confusion in this area, and if my use of the terms was a little loose, it was in an attempt to accommodate these misconceptions.
>
> To your second point, I once again didn't mean to imply anything erroneous about synchronous technology. I felt it deserved a mention in this article, but I couldn't devote as much time to exploring it as fully as I might have liked. I apologize for any confusion that resulted from my brief treatment. (To anyone interested in learning more about synchronous technology, I highly encourage you to read Matt's thorough ebook, linked in the article).
>
> And lastly, I wasn't trying to come down on one side or the other! I just meant to open that door for readers to ponder for themselves. Who knows what the future will bring? My crystal ball's been broken since November 2016.
>
> ▲ ▼ • Reply • Share ›

Dusko Radakovic • 6 months ago

When you say you have a 1000 feature model, and you want to edit the first feature (like the change in the diameter from 0.5in to 0.rin) the result will be a 1001st feature. Well, that could be true for Solidworks, but not for Creo or Pro/Engineer. In Creo Parametric when you want to change a feature (value, dimension scheme, or complete geometry) it does not create a new feature, rather edits the existing and regenerates to the 1000 feature. Changing, as editing, will not create a new feature in Creo, or Pro/E.

▲ ▼ • Reply • Share ›

bruce shand • 10 months ago

One thing not mentioned is the ability to edit "dumb" data. Things like data from vendors or customers not using your CAD software. Step, IGES files, etc. With Synchronous Tech you can immediately delete features, recognize certain features, add dimensions as reference or driving, push and pull faces. In other words with synchronous they become "smart".
For me, this is the most powerful part.
With history based modelers you can only cut away and add features to a "dumb" model, thereby adding back parent/child dependent features to a history tree with a fixed dumb parent feature at the top.

▲ ▼ • Reply • Share ›

Wolfgang Hofer • 10 months ago

There is a big difference between Creo Direct and Creo Elements/Direct Modeling.
Creo Direct has its parametric kernel, Creo Elements/Direct has its own kernel.
Creo Direct soon will have release 5.0, Creo Elements/Direct Modeling release 20.1.
A lot of ideas realized in Creo Elements/Direct you will find ind Creo Direct and the other direct modeler. PTC a few years ago named Creo Elements/Direct (former SolidDesigner) the best in class solution for direct modeling.

▲ ▼ • Reply • Share ›

> **Michael Alba** ➚ Wolfgang Hofer • 10 months ago
>
> Good call! Thanks for the note.
>
> ▲ ▼ • Reply • Share ›

Wolfgang Hofer • 10 months ago

You forgot to name the best direct modeler. Creo Elements/Direct Modeling - former SolidDesigner.

▲ ▼ • Reply • Share ›

Lardo140 • 10 months ago

How about listing KeyCreator (formerly called Cadkey) among those direct modelers? As KeyCreator was pretty much the first (And some of us still think the best.) direct modeler out there. KeyCreator also allows "dimension" changes, using their "Direct Dimension Editing". (Among a myriad of other ways to move geometry, including being able to push/pull faces.)

By the way, while IronCAD does have direct modeling capabilities, it also has history based modeling. Making it a "hybrid" modeler.

"Over time, however, as new generations of engineers enter the world of CAD modeling, perhaps the old history-based methods will give way to something more like synchronous technology, and the distinction between parametric and direct modeling may no longer be relevant."
Not likely. And here's why. The major players, like Autodesk and Dassault, give their software away

to the colleges and tech schools. (Just last summer Dassault partnered with the Experimental Aircraft Association to provide Solidworks free to it's members. And I'm sure they didn't do it out of the goodness of their hearts.) That's what new engineers learn on. Therefore, that's all they know. Solidworks and AutoCAD have them hooked from the start. It's kinda like the way pushers get new "customers" hooked on drugs.

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Michael Alba ➚ Lardo140 • 10 months ago

Thanks for the comment! I've added KeyCreator to the direct modeler list as per your suggestion, and marked IronCAD's inclusion in the history-based column. You might be right about Autodesk and Dassault's strategy of hooking them while they're young, but I think engineers are getting more and more adaptable. They'll have to, at the rate things seem to be changing!

Reply • Share ›

Wray Scott • 10 months ago

There is another aspect of this discussion that you have over looked, model size. As you mentioned in your article what you use can be influenced by what you are creating. Large models will kill some of the more generalized packages. I am defining large models as model assemblies that have part numbers in excess of 500-1000 parts. Think of a complete engine with its accessories. The best I have seen at managing larger models is Creo followed by probably Catia.

The reason I bring this up is that rarely do you just create a single part. It is usually that part and others that relate to each other. So if you push/pull it change a dimension you are effecting some other part or parts.

I will admit here that I came up in the history based era and really only consider direct modeling a step in the right direction but not really there technically. (I know that statement will get a rise.) I have only seen it used in parts. I have never seen it used in an assembly showing impact of the change you are making. You show the graphic that looks like a piston arm. You can't make that change without considering the related parts. That is where I question the "parametrics" of direct modelers. I could

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matt lombard ➚ Wray Scott • 10 months ago

Wray,
You're confusing "parametrics" with "associativity". Parametrics is changing with parameters - dimensions. Associativity is links or relationships between files.

Synchronous has the ability to change parts together in the assembly.

The part that no one has still mentioned is that Synchronous is not just "amped up direct modeling", but it also allows for old-fashioned history-based modeling as well, so you can do one or the other or both. Models can be mixed mode synchronous and history-based. There are some things where ordered parent/child type modeling is the way to go, and that's entirely possible.

The big problem with history-based modeling is not necessarily the order of the features, although that's an artifact from a computing age long passed, but more than anything, the problem is the parent/child relationships. How many times in a history-based model when editing do you curse the relationships that you then need to go back and disconnect, or re-link to something else.
Synchronous allows you to create relationships when you need them without being encumbered by them when they do more harm than good. It just makes sense. If you took the time to look into the synchronous method, you'd see that the marketing far undersells it. Marketing doesn't even know how to talk about it.

I was a hard-core history guy, wrote the SolidWorks Bible books, and lived with the software for nearly 20 years. Synchronous offers ways to work with 3D models that history modeling doesn't. Just out of curiosity, you ought to have a look at it.

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Wray Scott ➚ matt lombard • 10 months ago

Matt you may be right in a sense but when you are talking assemblies those words can be interchangeable. Think of a robotic arm with 4 segments. You have a base location, an end location plus a space limitation. Change a "parameter" on one of the inner linkages it will effect the length on the other linkages. You can classify that as associations or parameters.

As far as Synchronous technology goes i have not been impressed. Granted I have spent more time on history based systems but I was trained on NX and used it exclusively for 6 months. I still came into the situations where I needed to make a change in order of features and NX wouldn't/couldn't do it.

With that said I think that historical systems better mimic the real world manufacturing process not completely but much better than direct modeling systems. I mean how many times has a designer/engineer designed some thing that was not reasonably able to be manufactured. I see that more possible with the direct modeling process but that is just an opinion.

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