

# **REPLICATION**

**VS**

# **REPRODUCIBILITY**

# **REPLICATION**

Repeated experiment

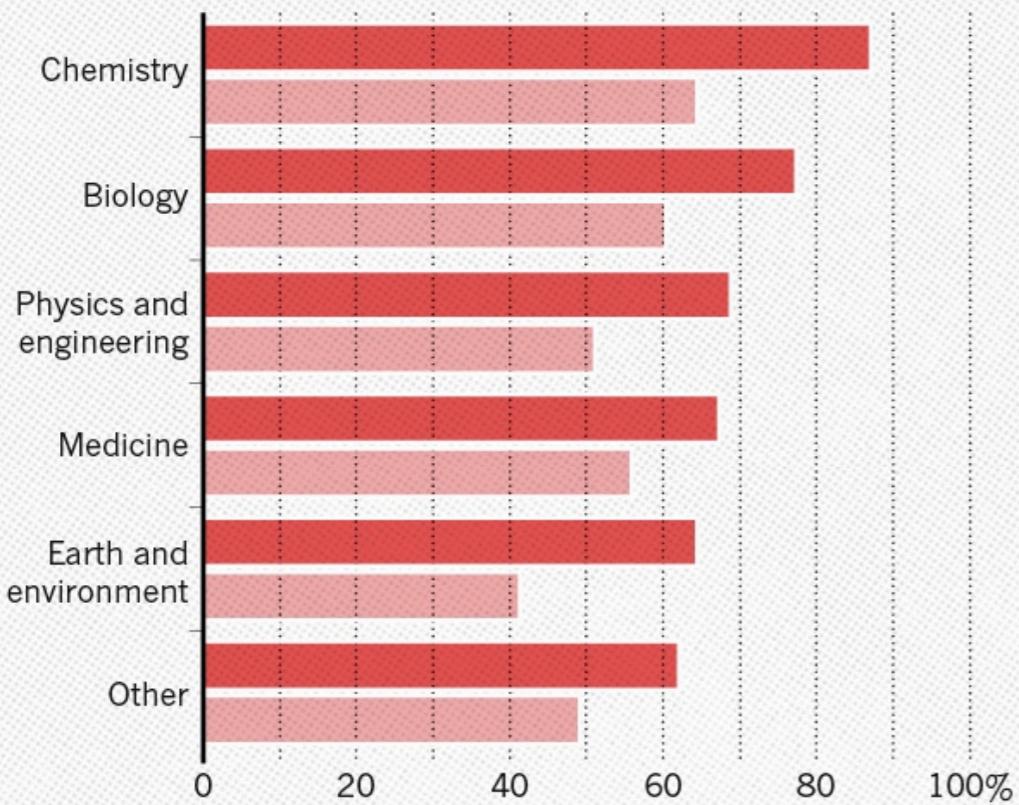
# **REPRODUCIBILITY**

**EXACT REPRODUCTION of the experiment**

## HAVE YOU FAILED TO REPRODUCE AN EXPERIMENT?

Most scientists have experienced failure to reproduce results.

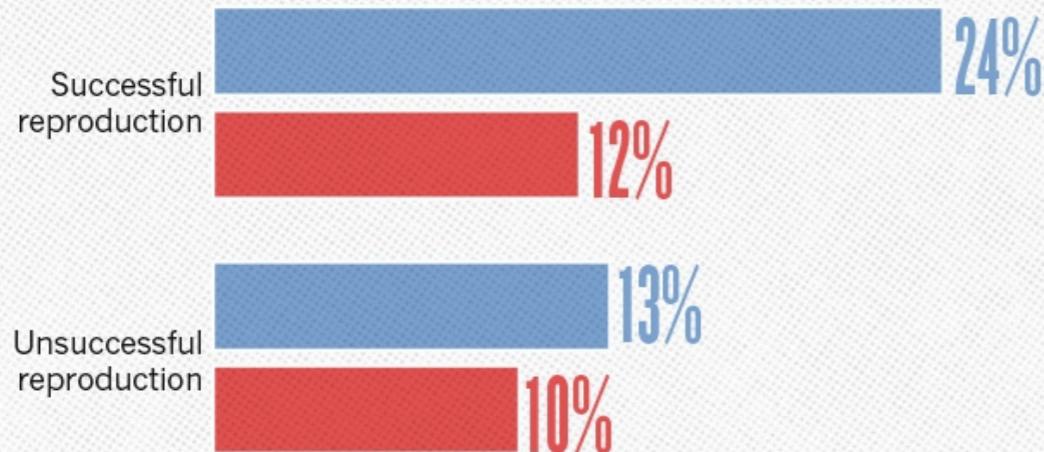
● Someone else's ● My own



## HAVE YOU EVER TRIED TO PUBLISH A REPRODUCTION ATTEMPT?

Although only a small proportion of respondents tried to publish replication attempts, many had their papers accepted.

● Published ● Failed to publish



Number of respondents from each discipline:

Biology 703, Chemistry 106, Earth and environmental 95,  
Medicine 203, Physics and engineering 236, Other 233

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<https://www.nature.com/news/1-500-scientists-lift-the-lid-on-reproducibility-1.19970>

The reproducibility crisis in science.

About 50% of big papers are not reproducible!

## RESEARCH ARTICLE SUMMARY

## PSYCHOLOGY

# Estimating the reproducibility of psychological science

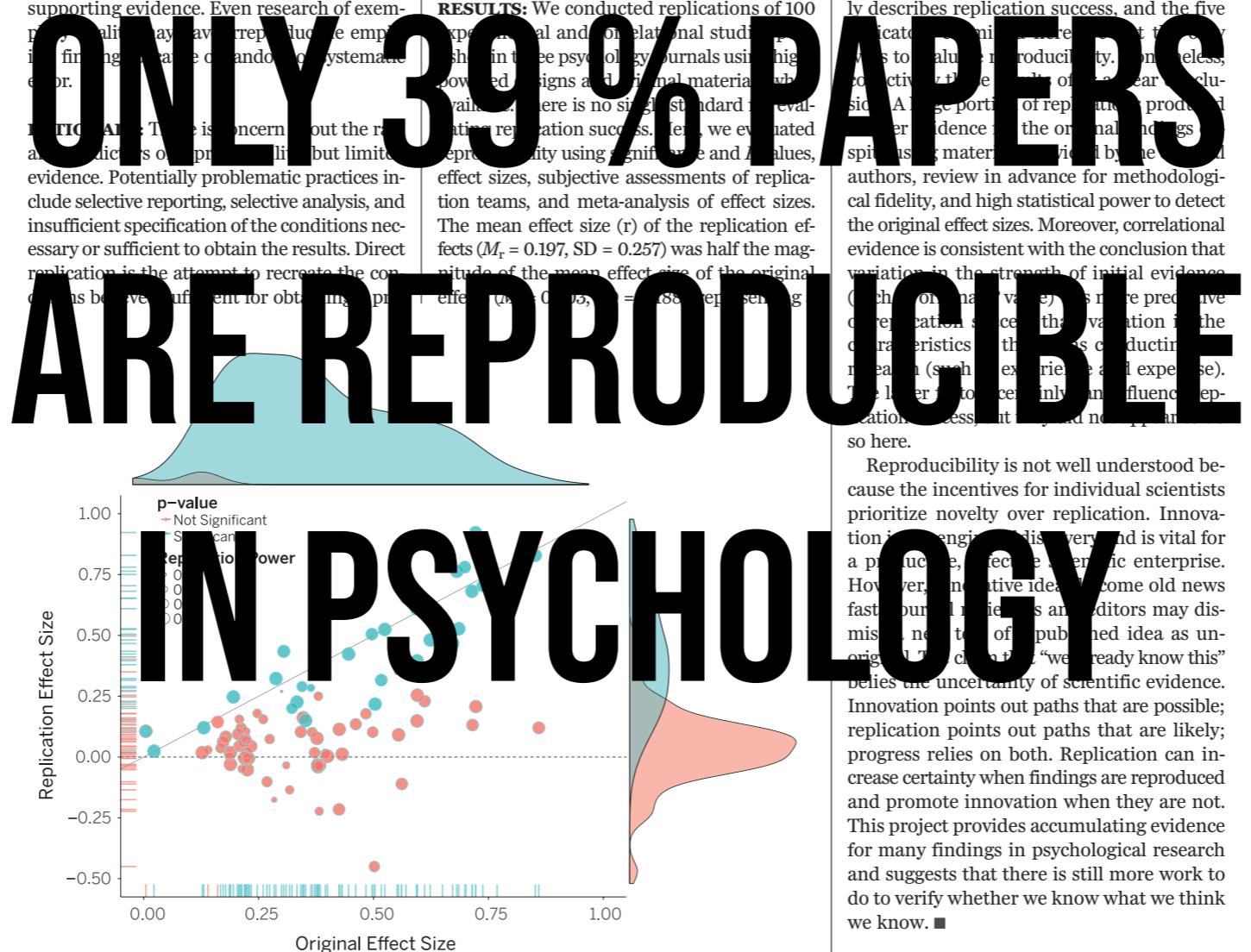
Open Science Collaboration\*

**INTRODUCTION:** Reproducibility is a defining feature of science, but the extent to which it characterizes current research is unknown. Scientific claims should not gain credence because of the status or authority of their originator but by the replicability of their supporting evidence. Even research of exemplary quality may have replicate the empirical findings of a colleague or systematic error.

**PRACTICALITY:** There is concern about the replicability of psychological results but limited evidence. Potentially problematic practices include selective reporting, selective analysis, and insufficient specification of the conditions necessary or sufficient to obtain the results. Direct replication is the attempt to recreate the conditions believed sufficient for obtaining pri-

viously observed finding and is the means of establishing reproducibility of a finding with new data. We conducted a large-scale, collaborative effort to obtain an initial estimate of the reproducibility of psychological science.

**RESULTS:** We conducted replications of 100 experiments from 126 original studies published in three psychology journals using high-powered designs and original materials where available. There is no single standard for evaluating replication success. Here, we evaluated replicability using significance and  $\lambda$  values, effect sizes, subjective assessments of replication teams, and meta-analysis of effect sizes. The mean effect size ( $r$ ) of the replication effects ( $M_r = 0.197$ ,  $SD = 0.257$ ) was half the magnitude of the mean effect size of the original effects ( $M_o = 0.393$ ,  $SD = 0.185$ ), representing



**Original study effect size versus replication effect size (correlation coefficients).** Diagonal line represents replication effect size equal to original effect size. Dotted line represents replication effect size of 0. Points below the dotted line were effects in the opposite direction of the original. Density plots are separated by significant (blue) and nonsignificant (red) effects.

substantial decline. Ninety-seven percent of original studies had significant results ( $P < .05$ ). Thirty-six percent of replications had significant results; 47% of original effect sizes were in the 95% confidence interval of the replication effect size; 39% of effects were subjectively rated to have replicated the original result;

and if no bias in original results is assumed, combining original and replication results left 68% with statistically significant effects. Correlational tests suggest that replication success was better predicted by the strength of original evidence than by characteristics of the original and replication teams.

**CONCLUSION:** No single indicator sufficiently describes replication success, and the five indicators examined here do not fully allow us to evaluate reproducibility. Nonetheless, collectively, these results offer a clear conclusion. A large portion of replication produced weaker evidence than the original findings despite using materials provided by the original authors, review in advance for methodological fidelity, and high statistical power to detect the original effect sizes. Moreover, correlational evidence is consistent with the conclusion that variation in the strength of initial evidence (such as  $p$  value) is more predictive of replication success than variation in the characteristics of the team conducting replication (such as experience and expertise). The lower rates of certainty in influence replication success, but they did not appear so here.

Reproducibility is not well understood because the incentives for individual scientists prioritize novelty over replication. Innovation is engines of discovery and is vital for a productive, fecund scientific enterprise. However, innovative ideas often become old news fast. Journal reviewers and editors may dismiss a need to re-publishe a published idea as unoriginal. The claim that "we already know this" belies the uncertainty of scientific evidence. Innovation points out paths that are possible; replication points out paths that are likely; progress relies on both. Replication can increase certainty when findings are reproduced and promote innovation when they are not. This project provides accumulating evidence for many findings in psychological research and suggests that there is still more work to do to verify whether we know what we think we know. ■

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**The unspoken rule is that at least 50% of the studies published even in top tier academic journals – Science, Nature, Cell, PNAS, etc... – can't be repeated with the same conclusions by an industrial lab. In particular, key animal models often don't reproduce.**

<https://lifescivc.com/2011/03/academic-bias-biotech-failures/>

**I**ncepit lib**re** bre ser let qui nos gra me ser dic im ur .  
**A** principio creauit deus celum. et per et terram. Terra autem erat manis et vacua: et tenebre erant super faciem abissi: et spiritus de*i* se rebatur super aquas. **D**ixitque deus. fiat lux. Et facta est lux. **E**t vidit deus lucem quod esset bona: et divisit lucem a tenebris. appellauitque lucem diem et tenebras noctem. **F**actum est vespere et mane dies unus. **D**ixit quoque deus. fiat firmamentum in me-  
dio aquarū: et dividat aquas ab a-  
quis. **E**t fecit deus firmamentum: diui-  
sioque aquas que erant sub firmamen-  
to ab his que erant super firmamen-  
tum: et factum est ita. **V**ocauitque deus  
firmamentum celū: et factum est vespere  
et mane dies secundus. **D**ixit vero de-  
us. Longegetur aque que sub celo  
sunt in locum unū: et appareat arida. **E**t factum est ita. **E**t vocauit deus ari-  
dam terram: cōgregatiōnesque aquarū  
appellauit maria. **E**t vidit deus quod es-  
set bonū: et ait. **E**reminet terra herbā  
virentem et faciente al semeni: et lignū  
pomiferū faciens fructū iuxta genū  
sū: cuius semen in semetipso sit super  
terram. **E**t factum est ita. **E**t produlit  
terra herbam virentem et affligeretque se-  
men iuxta genū suū: lignūque: semenē scđm  
specie suā. **E**t vidit deus quod esset bonū:  
et factū est vespere et mane dies tertius. **D**ixitque aut̄ deus. fiat luminaria  
in firmamento celī: et dividat diem ac  
noctē: et sunt in signa et temporā: et dies et  
annos: ut lucent in firmamento celī et  
illuminent terrā. **E**t factū est ita. **F**ecitque  
deus duo luminaria magna: lumina-  
re manus ut presset dici et lumina-  
re minū: ut presset nodi: et stellas: et posuit eas in  
firmamento celī ut lucent sup terrā: et

pellent diui ac nocti: et diuident lucem  
ac tenebras. **E**t vidit deus q[uod] esset bonum;  
et factum est vespero et mane dies quartus.  
**D**ixit etiam deus. Producant aque  
reptile animae viventis et volatile super  
terram: sub firmamento celi. **C**reavitque  
deus cete grandia: et omnem animam vi-  
uentem atque notabilem quam produxe-  
rant aque in species suas: et omne vo-  
latile secundum genus suum. **E**t vidit de-  
us q[uod] esset bonum: benedixitque ei dicens.  
**C**reescite et multiplicamini: et replete a-  
quas maris: auesque multiplicentur  
super terram. **E**t factum est vespero et mane  
dies quintus. **D**ixit quoque deus. Pro-  
ducat terra animam viventem in gene-  
re suo: numenta et reptilia: et bestias ter-  
re. secundum species suas. **F**actum est ita. **E**t  
fecit deus bestias terre iuxta species su-  
as: numenta et omne reptile terre in ge-  
nere suo. **E**t vidit deus q[uod] esset bonum:  
et ait. **F**aciam hominem ad ymaginem et  
similitudinem nostram: et pluit pisibus maris:  
et volantibus celi: et bestiis: uniusque terre:  
omnique reptili q[uod] mouetur in terra. **E**t crea-  
uit deus hominem ad ymaginem et simili-  
tudinem suam: ad ymaginem dei crea-  
uit illum: masculum et feminam creauit eos.  
**B**enedixitque illis deus: et ait. **C**reescite u-  
nti multiplicamini et replete terram: et  
subicieite eam: et dominiamini pisibus  
maris: et volantibus celi: et uniuersis  
animatis que mouentur super terram.  
**D**ixitque deus. **E**cce dedi vobis omnem:  
herbam afferentem semeni super terram:  
et uniuersa ligna que habent in semetipsis  
semel generis sui: ut sine vobis in escam:  
et cunctis animalibus terre: omnique volatile  
celi: et uniuersis que mouentur in terra: et in  
quibus est anima vives: ut habeatis ad  
vestendum. **E**t factum est ita. **V**idinq[ue] deus  
cuncta que fecerat: et erat valde bona.

Hermann Zapf (1918 - 2015)



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# The Art of Computer Programming

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Third Edition

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DONALD E. KNUTH

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Donald E Knuth (1938 -)

# *«Literate Programming»*

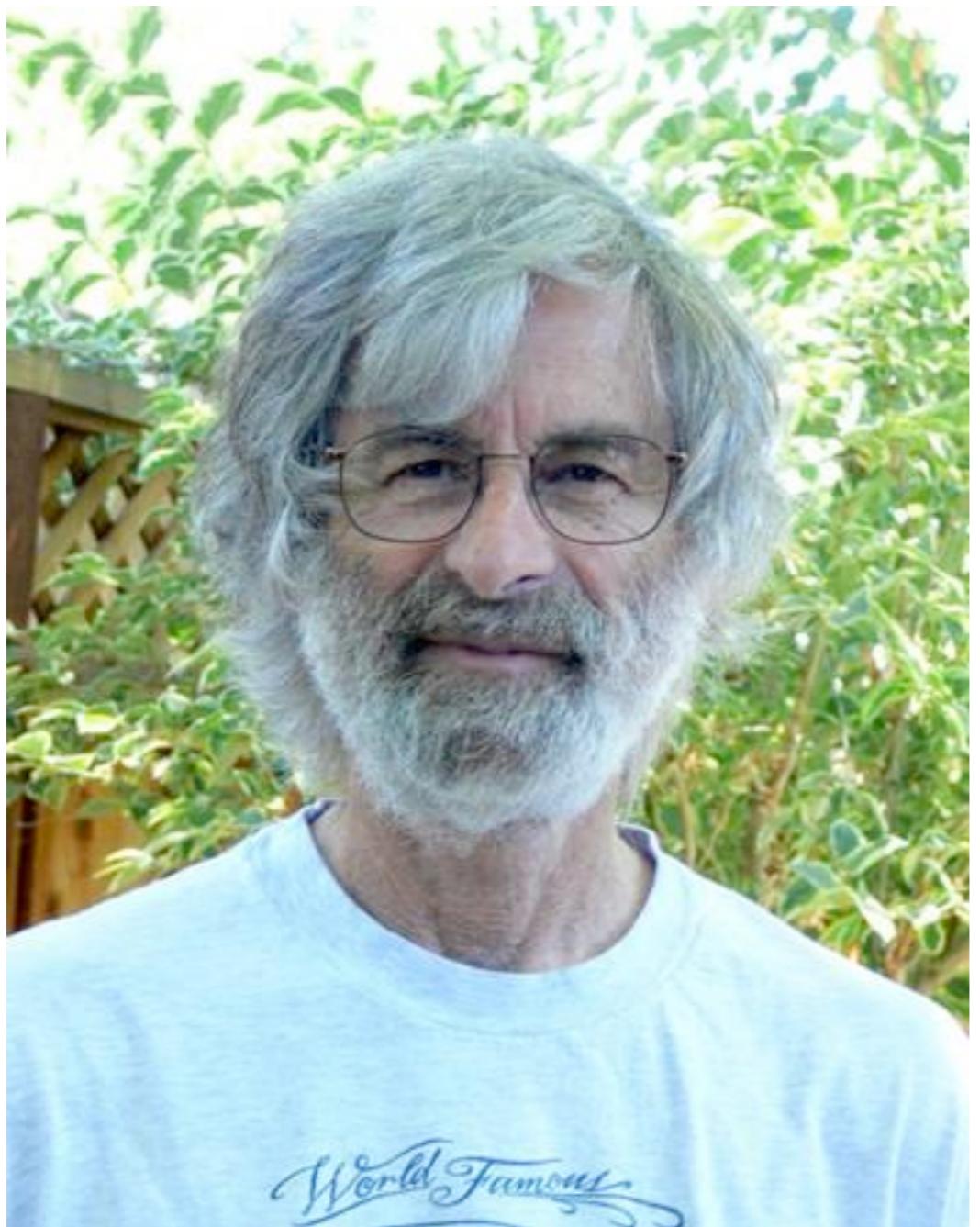


Donald E. Knuth

• Emphasizes documentation.  
• Encourages writing code of small, large, simple, and  
• Clear descriptions of it.  
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• While programming, writing, the  
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Plenum Publishing Corporation

**T<sub>f</sub>X**



**LATEX**

Leslie Lamport (1938 -)



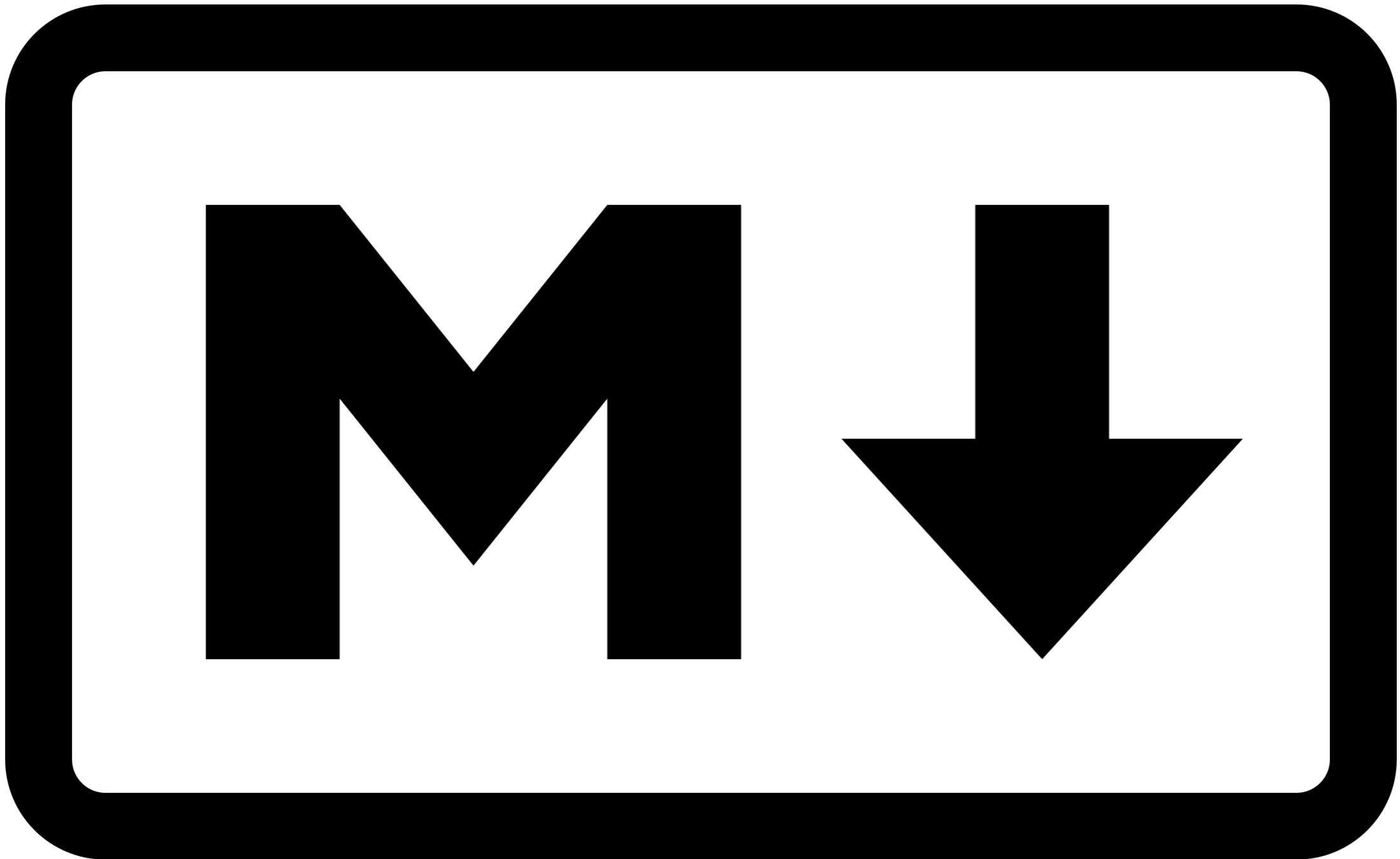
pdfTeX

Hàn Thế Thành (1972 -)



XΕΤΕΧ

Jonathan Kew ( ? -)



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