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TCD-SCSS-V.20190910.007	Ed: Bubak, M., Turala, M., Wiatr, K., Proc.Cracow '04 Grid Workshop, proceedings of workshop in Cracow, Poland, Dec-2004, ISBN 83-915141-4-5, CYFRONET, 2005.
TCD-SCSS-V.20190910.008	Ed: Bubak, M., Turala, M., Wiatr, K., Proc.Cracow '05 Grid Workshop, proceedings of workshop in Cracow, Poland, Nov-2005, ISBN 83-915141-5-3, CYFRONET, 2006
TCD-SCSS-V.20190910.009	Ed: Bubak, M., Turala, M., Wiatr, K., Proc.Cracow '06 Grid Workshop, proceedings of workshop in Cracow, Poland, Dec-2006, Vol.1 ISBN 978-83-915141-7-X, Vol.2 ISBN 978-83-915141-8-4, CYFRONET.
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References:

1. Wikipedia, *Grid computing*, see:
https://en.wikipedia.org/wiki/Grid_computing
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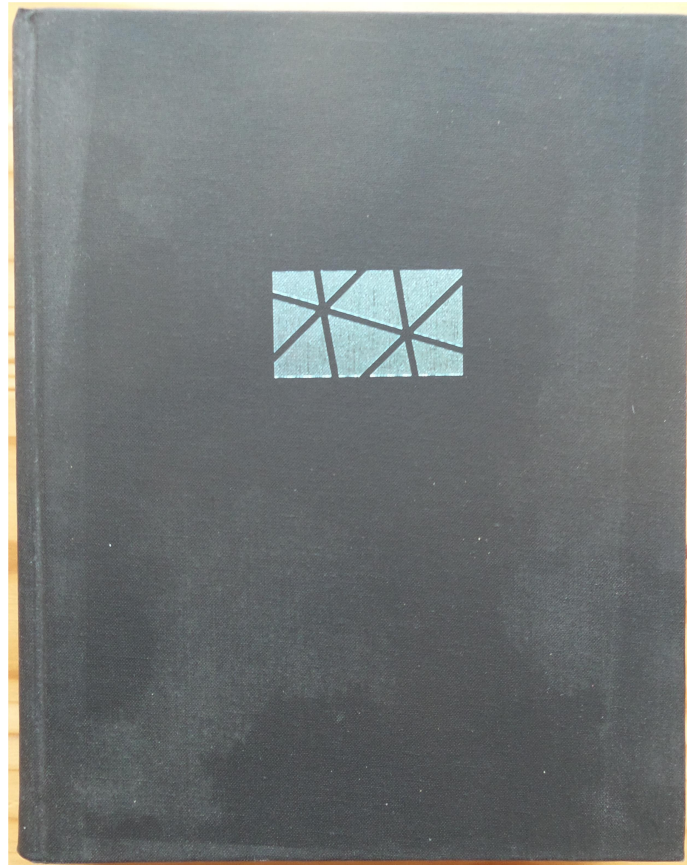


Figure 1: The Grid: Blueprint for a New Computing Infrastructure, Front Cover

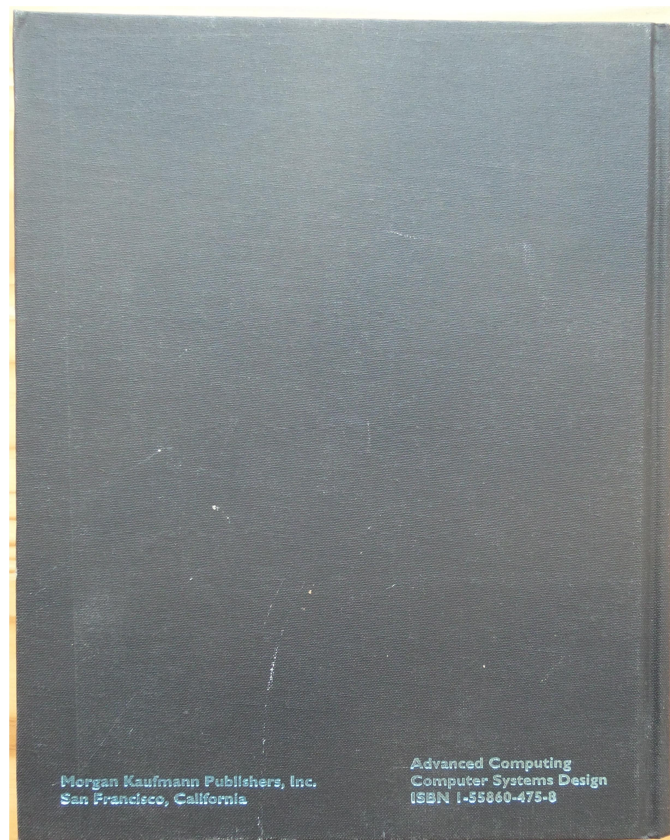


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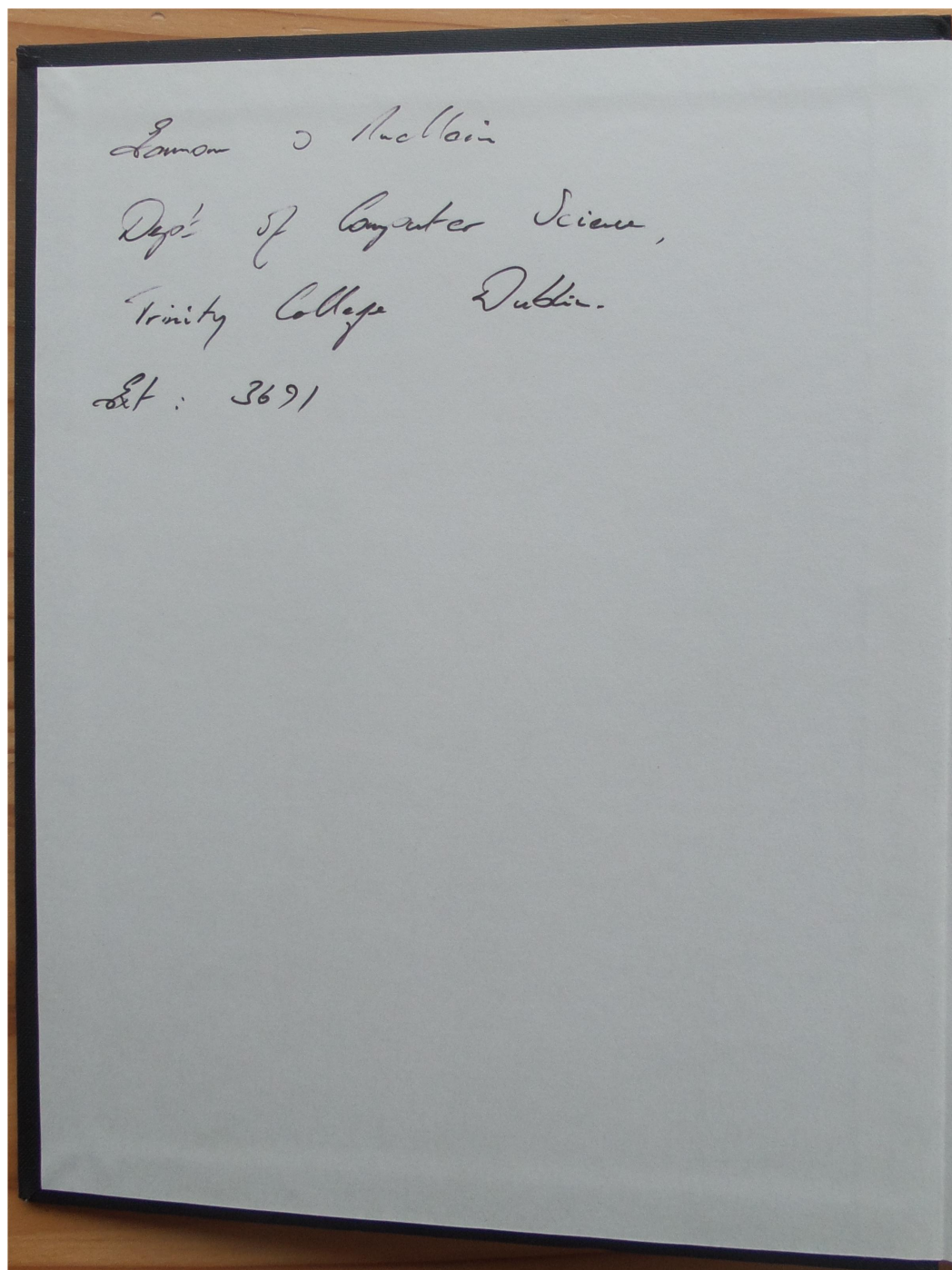


Figure 4: The Grid: Blueprint for a New Computing Infrastructure, inside front cover

The Grid: Blueprint for a New Computing Infrastructure

Edited by

Ian Foster

Argonne National Laboratory
and the University of Chicago

Carl Kesselman

Information Sciences Institute,
University of Southern California



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Figure 5: *The Grid: Blueprint for a New Computing Infrastructure*, Title Pages page 1

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