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Annotated Z bibliography

Jonathan Bowen
Oxford University Computing Laboratory, Wolfson Building, Parks Road, Oxford OX1 3QD, UK

Susan Stepney and Rosalind Barden
Logica Cambridge Limited, Betjeman House, 104 Hills Road, Cambridge CB2 1LQ, UK

Introduction

This annotated Z bibliography contains a selected list of some pertinent publications for Z users. Most of those included are readily available, either as books or in journals. A few unpublished items have been included, where they are particularly relevant and can be obtained reasonably easily.

Some references are accompanied by an annotation. This may include a contents list (of a book), a list of the titles of Z related papers (in a collection) with cross-references to the full details, or a summary of the work.

Cross-references

The bibliography in the last section lists all references in alphabetical order by author. In this section papers are arranged by subject (with authors and brief details of the subject matter), together with cross-references to the full details in the bibliography.

Management, style, and method

For justifications for using formality, and quick introductions to Z, see:

Cohen/McDermid. Justification of formal methods and notations[63,199].
Meyer. On formalism in specifications[204].
Spivey. Introduction to Z[269].
Wing. General introduction to formal methods including Z[305,306].
Woodcock. Structuring specifications[311].

For discussion about using formal methods in practice, see:

Barden *et al.* *Z in practice*[20].
Barroca/McDermid, Bowen/Stavridou and Gerhart *et al.* Formal methods and safety-critical systems[22,45,46,118,201].
Gerhart. Applications of formal methods[116].
Hall and Bowen/Hinchey. Myths and guidance about formal methods[124,40,41,42].
Worden. Fermenting and distilling ideas[319].

Educational issues are presented and discussed in:

Cooper. Educating management[68].
Garlan. Effective integration of formal methods into a professional master of software engineering course[113].
Saiedian. The mathematics of computing[252].
Swatman. Educating information systems professionals[290].

Various papers describing good specification style are:

Ainsworth *et al.* The use of viewpoint specifications, a technique which concentrates on making large specifications more understandable[6].
Duke. Enhancing structure[92].
Gravell. Minimization in specification/design and what makes a good specification[122,123].
Macdonald. Usage and abusage[189].

Much work has been done on attempting to integrate Z with traditional structured analysis methods. Some of this is described in:

Aujla *et al.* A rigorous review technique[14].
Bryant *et al.* Structured methodologies and formal notations[55].
Draper. Z and SSADM[90].
Giovanni and Iachini. HOOD and Z[83].
Polack *et al.* SAZ Method—Structured analysis and Z[238–240].
Josephs and Redmond-Pyle. Entity-relationship models, structured methods, and Z[165,166].
Randell. Data flow diagrams and Z[245,246].
Semmens and Allen. Yourdon and Z[256].
Semmens *et al.* Integrated structured analysis and formal specification techniques[257].
van Hee *et al.* Petri nets and Z[299].

Other work towards the development of a 'method' for Z itself include:

Barden *et al.* Z in practice[20].
Hall and McDermid. Towards a Z method using axiomatic specification in Z (using order sorted algebra and OBJ3 in particular)[127].
Neilson. A rigorous development method from Z to C[219].

Wood. A practical approach using Z and the refinement calculus[308].
Wordsworth. Software development with Z[321].

The application of metrics to formal specifications has been studied:

Whitty and Bainbridge *et al.* Structural metrics for Z specifications[302,17].

A formal specification in Z can be useful for deciding test cases, etc. Work on testing is reported in:

Ammann and Offutt. Functional and test specifications based on the category-partition method[8,9].
Carrington and Stocks. Formal methods and software testing[60].
Cusack and Wezeman. Deriving tests for objects specified in Z[77].
Hall. Testing with respect to formal specification[128].
Hayes. Specification directed module testing[133].
Stocks. Applying formal methods to software testing[281].
Stocks and Carrington. Deriving software test cases from formal specifications[282].
Stocks and Carrington. Test templates: a specification-based testing framework and case study[283,284].

Application areas

Surveys of formal methods, including Z users, are reported in:

Austin and Parkin. Formal methods: a survey[15].
Barden *et al.* Use of Z (in the UK)[19].
Craigen *et al.* An international survey of major industrial formal methods applications, including a number using Z[71–73,117,118].

One of the high profile users of Z is IBM UK Laboratories at Hursley for specification and development of the CICS transaction processing system. General descriptions of the CICS project include:

Collins *et al.* Introducing formal methods: the CICS experience with Z[64].
Houston and King. CICS project report[147].
Nix and Collins. Use of software engineering and Z in the development of CICS[228].
Phillips. CICS experience throughout the lifecycle[235].
Wordsworth. The CICS application programming interface (API) definition[320].

Specifying secure systems is discussed in:

Jones. Verification of critical properties[160].
Smith and Keighley. A secure transaction mechanism (SWORD secure DBMS)[267].

Not all Z specifications are of software systems. Much interesting and important work has been done on formally specifying hardware, including microprocessors. The Inmos T800 transputer Floating Point Unit microcode development is a major real example where formal methods have saved time by reducing the amount of testing needed.

May. Shepherd *et al.* T800 transputer FPU development[196–198,260,261].

More technical papers on hardware applications (including embedded software) are:

Barrett. A floating-point number system (IEEE standard)[21].
Bowen. Microprocessor instruction sets (Motorola M6800 and transputer)[29,30,33].
Delisle/Garlan and Hayes. Oscilloscopes, including reuse of specifications[81,82,114,135].
Kemp. Viper microprocessor[167,168].
Smith and Duke. Cache coherence protocol (in Object-Z)[266].
Spivey. Real-time kernel[271].

Communications systems and protocols are specified in:

Bowen *et al.* Network services via remote procedure calls (RPC)[29].
Butler. Service extension (PABX)[57].
Duke *et al.* Protocol specification and verification using Z[95].
Duke *et al.* Object-oriented protocol specification (mobile phone system, in Object-Z)[98].
Gotzhein. Open distributed systems[121].
Haughton. Safety and liveness properties of communication protocols[132].
Mataga and Zave. Formal specification of telephone features[194].
Pilling *et al.* Inheritance protocols for real-time scheduling[236].
Till and Potter. Gateway functions within a communications network[293].
Zave and Jackson. Specification of switching systems (PBX)[323].

The following papers describe the use of Z for various graphics applications, standards (especially GKS), and human computer interfaces:

Abowd *et al.* A survey of user interface languages including Z[2].
Arnold *et al.* Configurable models of graphics systems (GKS)[10,11].
Bowen. Formal specification of window systems (X in particular)[31,34].
Brown and Bowen. An extensible input system for Unix[53].
Dix *et al.* Human–Computer Interaction (HCI)[88].
Duce *et al.* Formal specification of *Presentation Environments for Multimedia Objects* (PREMO)[91].
Harrison. Engineering human-error tolerant software[130].
Johnson. Specification and prototyping of concurrent multi-user interfaces[156].
Johnson and Harrison. Declarative graphics and dynamic interaction[157].
Narayana and Dharap. Formal specification of a look manager and a dialog system[214,215].
Nehlig and Duce. Formal specification of the GKS design primitive[217].
Sufrin. Formal specification of a display-oriented editor[287].
Sufrin and He. Effective user interfaces and interactive processes[286,289].
Took. A formal design for an autonomous display manager[294].

An important application area for formal methods is safety-critical systems where human lives may depend on correctness of the system.

Barroca/McDermid, Bowen/Stavridou and Gerhart *et al.* Surveys covering formal methods and safety-critical systems[22,45,46,118,201].
Bowen *et al.* Safety-critical systems and standards[35,39,46].
Knight and Littlewood. Special issue of *IEEE Software on Safety-Critical Systems*[173].
Place and Kang. Safety-critical software: status report and annotated bibliography[237].

Some examples of the application of Z to safety-critical systems are in:

Jacky. Formal specifications for a clinical cyclotron[152–154].
Knight and Kienzle. Using Z to specify a safety-critical system in the medical sector[172].
Ruddle. Specification of real-time safety-critical control systems[250].

Other papers describing a variety of applications using Z include:

Abowd *et al.* Software architectures[1].
Bowen. A text formatting tool[32].
Bowen, Lano and Breuer. Reverse engineering[36,178].
Brownbridge. CASE toolset (for SSADM)[54].
Butcher. A behavioural semantics for Linda-2[56].
Craig. Specification of advanced AI architectures[70].
de Barros and Harper. Formal specification and derivation of relational database applications[78,79].
Fenton and Mole. Flowgraph transformation[104].
Morgan and Sufrin. Specification of the Unix filing system[209].
Nash. Large systems[216].
Reizer *et al.* Requirements specification of a proposed POSIX standard[248].
Stepney. High integrity compilation[276].
Sufrin. A Z model of the Unix *make* utility[288].
Woodcock *et al.* Formal specification of the UK Defence Standard 00-56[315].
Zhang and Hitchcock. Designing knowledge-based systems and information systems[325].

Textbooks on Z

Diller. Z: an introduction to formal methods (2nd edn)[86].
Hayes *et al.* Specification case studies (the first book on Z, now in its 2nd edition, containing an excellent selection of example Z specifications)[139].
Imperato. An introduction to Z[149].
Ince. An introduction to discrete mathematics and formal system specification (2nd edn)[150].
Lightfoot. Formal specification using Z[183].
McMorran and Powell. Z guide for beginners[202].
Norcliffe and Slater. Mathematics of software construction[229].
Potter, Sinclair and Till. An introduction to formal specification and Z (a popular first textbook on Z)[241].
Ratcliff. Introducing specification using Z[247].
Woodcock and Loomes. Software engineering mathematics[317].
Wordsworth. Software development with Z[321].

A video course is also available[230,231].

Language details

Z's syntax, semantics and mathematical toolkit are being internationally standardized under ISO/IEC JTC1/SC22. A draft version of the standard is available:

Brien and Nicholls. Z Base Standard, version 1.0[52].

The definition of the Z syntax and mathematical toolkit used by many practitioners are in:

Spivey. Z reference manual (2nd edn)[273].

More technical works describing Z's formal semantics are in:

Gardiner *et al.* A simpler semantics[112].
Spivey. Understanding Z[268].
Spivey and Sufrin. Type inference[274].
van Diepen and van Hee. The link between Z and the relational algebra[298].

Z is often compared and contrasted with VDM (Vienna Development Method). The following papers show the cross-fertilization and comparisons between the two:

Bera. Structuring for the VDM specification language, in response to the Z schema notation[26].
Gilmore. Correctness-oriented approaches to software development in which the Z, VDM and algebraic styles are compared[119].
Hayes. A comparative case study of VDM and Z[138].
Hayes *et al.* Understanding the differences between VDM and Z[141].
Lindsay. A VDM perspective on reasoning about Z specifications and transferring VDM verification techniques to Z[184,185].
Lindsay and van Keulen. Case studies in the verification of specifications in VDM and Z[186].
Monahan and Shaw. Model-based specifications, including a discussion of the respective trade-offs in specification between Z and VDM[206].

Reasoning about Z specifications is addressed in:

Morgan and Sanders. Laws of the Logical Calculi[208].
Woodcock. Calculating properties (preconditions)[309].
Woodcock/Brien and Martin. $\mathfrak{W}$, a logic for Z[193,314].

Work on refining Z-like specifications towards an implementation (see also 'Conference proceedings' section later) includes:

Barrett. Refinement from Z to microcode via Occam[21].
Bailes and Duke. Class refinement[16].
Baumann. Z and natural semantics programming language theory for algorithm refinement[23].
Diller. Hoare logic[85] and Part II: *Methods of Reasoning* in[86].
Fidge. Real-time refinement and program development[107–109].
Gilmore. Correctness-oriented approaches to software development (Z, VDM and algebraic styles are compared)[119].
He *et al.* Foundations for data refinement[144].
Jacob. Varieties of refinement[155].

Josephs. Data refinement calculation for Z specifications[163].
King and Sørensen. Specification and design of a library system[171].
Lano and Haughton. Reasoning and refinement in object-oriented specification languages[177,180].
Mahoney/Hayes *et al.* Timed refinement[190–192].
Neilson. Hierarchical refinement of Z specifications and a rigorous development method from Z to C[218,219].
Sennett. Using refinement to convince (pattern matching in ML)[258].
Sennett. Demonstrating the compliance of Ada programs with Z specifications[259].
Sufrin and He. Specification, analysis and refinement of interactive processes[289].
Whysall and McDermid. Object-oriented specification and refinement[304].
Wood. Software refinery[307].
Woodcock. Implementing promoted operations in Z[312].
Woodcock and Morgan. Refinement of state-based concurrent systems[318].
Wordsworth. Software development with Z[321].

The 'refinement calculus' approach to refinement is espoused in:

King. Z and the refinement calculus[170].
Morgan. A standard student textbook (2nd edn)[207].
Morgan and Vickers. Collected research papers[210].
Wood. A practical approach using Z and the refinement calculus[308].

The related B-Method, with associated B-Tool, B-Toolkit and Abstract Machine Notation (AMN), have been developed by Abrial *et al.*, also the progenitor of Z:

Abrial. The B-Tool, B-Method and forthcoming B-Book[3–5].
Dehbonei and Mejia. Use of B in the railways signalling industry[80].
Diller and Docherty. A comparison of Z and Abstract Machine Notation[87].
Neilson and Prasad. zedB (a prototype B-based proof tool)[220,221].
Ritchie *et al.* Experiences in using the Abstract Machine Notation in a GKS graphics standard case study[249].
Storey and Haughton. A strategy for the production of verifiable code using the B-Method[285].

Execution of formal specifications is a subject of perennial debate. See:

Hayes and Jones. Specifications are not (necessarily) executable[140].

A retort may be found in:

Fuchs. Specifications are (preferably) executable[111].

Animating Z specifications is discussed in:

Breuer and Bowen. Correct executable semantics for Z using abstract interpretation, including an informal taxonomy of approaches[51].
Dick *et al.* Computer aided transformation of Z into Prolog[84].
Diller. Part IV: *Specification Animation* (using Miranda)[86].
Doma and Nicholl. EZ: automatic prototyping[89].
Goodman. Animating Z specifications in Haskell using a monad[120].
Hasselbring. Animation of Object-Z specifications with a set-oriented prototyping language[131].
Johnson and Sanders. Functional implementations (Z to Miranda)[158].
Love. Animating Z specifications in SQL[187].
Stepney and Lord. An access control system (Z to Prolog)[280].
Valentine. Z--, an executable subset of Z[296].
West and Eaglestone. Two approaches to animation (Z to Prolog)[300].

Specific language features are addressed in:

Arthan and Smith. Free types in Z (including recursion)[13,263].
Hayes. A generalization of bags[134].
Hayes. Interpretations of schema operators[136].
Hayes. Multi-relations in Z (a cross between multi-sets and binary relations)[137].
Lupton. Promotion and forward simulation[188].
Morgan and Sufrin. Schema framing[209].
Woodcock. Proof rules for promotion and implementing promoted operations[310,312].

Some research has been undertaken in using and adapting Z to model concurrent systems:

Coombes and McDermid. Specifying distributed real-time systems[66].
Evans. Visualizing, specifying and verifying concurrent systems using Z[101,102].
Johnson. Applying temporal logic to support the specification and prototyping of concurrent multi-user interfaces[156].
Lamport. TLZ: Temporal Logic of Actions (TLA) and Z[175].
Narayana and Dharap. Invariant properties in a dialog system[215].
Schuman *et al.* Object-oriented process specification[255].

In particular, there has been some work on combining Z and CSP (Communicating Sequential Processes), a formal process model with associated algebra for concurrent systems:

Benjamin. A message passing system: an example of combining CSP and Z[24].
Josephs. Theoretical work on a state-based approach to communicating processes[164].
Woodcock and Morgan. Refinement of state-based concurrent systems[318].

Researchers have also considered modelling and reasoning about real-time systems, for example, by combining temporal logic with Z:

Coombes and McDermid. Specifying temporal requirements for distributed real-time systems[66].
Duke and Smith. Temporal logic and Z specifications[99].
Engel. Specifying real-time systems with Z and the duration calculus[100].
Fergus and Ince. Model logic and Z specifications item[105].
Fidge. Specification and verification of real-time behaviour using Z and RTL[106].
Fidge. Real-time refinement and program development[107–109].

He Jifeng *et al.* Provably correct systems, including the use of Duration Calculus with schemas for structuring[143].
Johnson. Applying temporal logic to support the specification and prototyping of concurrent multi-user interfaces[156].
Lamport. TLZ: Temporal Logic of Actions (TLA) and Z[175].
Mahoney/Hayes *et al.* Timed refinement[190–192].
Narayana and Dharap. Invariant properties in a dialog system using Z and temporal logic[215].
Pilling *et al.* Inheritance protocols for real-time scheduling[236].
Ruddle. Specification of real-time safety-critical control systems[250].
Smith. An object-oriented approach including a formalization of temporal logic history invariants[264].

Conference proceedings

Regular Z User Meetings are organized by the Z User Group and have had published proceedings since the 4th meeting:

Nicholls. 4th Z User Meeting, Oxford, 1989[222].
Nicholls. 5th Z User Meeting, Oxford, 1990[224].
Nicholls. 6th Z User Meeting, York, 1991[226].
Bowen and Nicholls. 7th Z User Meeting, London, 1992[44].
Bowen and Hall. 8th Z User Meeting, Cambridge, 1994[38].
Bowen and Hinchey. 9th Z User Meeting, Limerick, 1995[43].

The regular Refinement Workshop is organized by BCS-FACS. Papers cover a variety of refinement techniques from specification to code, and include some Z examples:

McDermid. 1st Refinement Workshop, York, 1988[200].
Morgan and Woodcock. 3rd Refinement Workshop, Hursley, 1990[211].
Morris and Shaw. 4th Refinement Workshop, Cambridge, 1991[212].
Jones *et al.* 5th Refinement Workshop, London, 1992[160].
Till. 6th Refinement Workshop, London, 1994[292].

FME Symposia are held every 18 months, organized by Formal Methods Europe. These grew out of the later VDM-Europe conferences which included papers on Z:

Bloomfield *et al.* VDM'88, Dublin[28].
Bjørner *et al.* VDM'90, Kiel[27].
Prehn and Toetenel. VDM'91, Noordwijkerhout[242,243].
Woodcock and Larsen. FME'93, Odense[316].
Naftalin *et al.* FME'94, Barcelona[213].

Tools

The ZIP Project tools catalogue lists some tools that support formatting, checking and proof of Z specifications:

Parker. Z tools catalogue[234].

Details of individual tools may be found in:

Arthan. A proof tool based on HOL which grew into ProofPower (see below)[12].
Bowen and Gordon. Z and HOL (a tool based on higher order logic)[37].
Flynn *et al.* Formalizer (editor and type-checker)[110].
Jones. ICL ProofPower (a commercial tool based on HOL)[161].
Jordan *et al.* CADiZ (formatter and type-checker)[162,295].
Neilson and Prasad zedB (a prototype B-based schema expansion and precondition calculator tool)[220,221].
Saaltink. Z and EVES (a tool based on ZF set theory)[251].
Spivey. *fuzz* (a commercial LaTeX formatter and type-checker, 2nd edn)[272].
Xiaoping Jia. ZTC (a freely available type-checker)[322].

Object-oriented approaches

There has been much work recently to enhance Z with some of the structuring ideas from object-orientation. Overviews and comparisons can be found in:

Carrington. ZOOM workshop report[58].
Lano and Haughton. Object-oriented specification case studies, many using extensions to Z[181].
Stepney *et al.* Collected papers and a survey on object-orientation in Z[278,279].

Object-Z is the best-documented and probably most widely used object-oriented extension to Z. The definitive description of the language is:

Duke *et al.* Version 1 of Object-Z[97].

Other Object-Z papers include:

Carrington *et al.* Object-Z: an object-oriented extension to Z[59].
Duce *et al.* Formal specification of *Presentation Environments for Multimedia Objects* (PREMO)[91].
Duke and Duke. Towards a semantics[93].
Duke and Duke. Aspects of object-oriented specification (card game example)[94].
Duke *et al.* Object-oriented protocol specification (mobile phone system)[98].
Hasselbring. Animation with a set-oriented prototyping language[131].
Rafsanjani and Colwill. From Object-Z to C++[244].
Smith and Duke. Cache coherence protocol[266].

Descriptions of other object-oriented approaches in conjunction with Z may be found in:

Alencar and Goguen. OOZE: an object-oriented Z environment[7].
Chan and Trinder. An object-oriented data model supporting multi-methods, multiple inheritance, and static type-checking[62].
Cusack. Inheritance in object-oriented Z[75].
Hall. A specification calculus for object-oriented systems and class hierarchies in Z[125,126].
Hammond. Producing Z specifications from object-oriented analysis[129].
Lano/Haughton *et al.* Z^{++}: an object-oriented extension to Z[36,176,179].
Maung and Howse. Hyper-Z: a new approach to object-orientation[195].
Meira and Cavalcanti. MooZ: Modular object-oriented Z specifications[203].
Schuman, Pitt *et al.* Object-oriented subsystem and process specification[254,255].
Wezeman and Judge. Z for managed objects[301].
Whysall and McDermid. Object-oriented specification and refinement[303,304].

On-line information

The BIBTEX source for this bibliography and related information is available on-line via the World Wide Web under the following URL (Uniform Resource Locator):

http://www.comlab.ox.ac.uk/archive/z/bib.html

The bibliography is searchable. The user may provide a regular expression or select from a number of predefined keywords. Hyperlinks are included to documents that can be accessed on-line.

Acknowledgements

We would like to thank all those who suggested references for inclusion in this bibliography. It has been adapted from the ZIP project bibliography[277] and the on-line Z bibliography held at the Oxford University Computing Laboratory[48], including more recent additions.

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Bibliography

1 Abowd, G D, Allen, R and Garlan, D 'Using style to understand descriptions of software architectures', *ACM Software Engineering Notes* Vol 18 No 5 pp 9–20, (December 1993)

2 Abowd, G D, Bowen, J P, Dix, A J, Harrison, M D and Took, R 'User interface languages: a survey of existing methods'. Technical Report PRG-TR-5-89, Oxford University Computing Laboratory, Wolfson Building, Parks Road, Oxford, UK (October 1989)

3 Abrial, J-R 'The B tool', in Bloomfield *et al.*[28] pp 86–87

4 Abrial, J-R 'The B method for large software, specification, design and coding (abstract)', in Prehn and Toetenel[243] pp 398–405

5 Abrial, J-R *The B-Book*. Cambridge University Press (To appear)

Contents: Mathematical reasoning; Set notation; Mathematical objects; Introduction to abstract machines; Formal definition of abstract machines; Theory of abstract machines; Constructing large abstract machines; Example of abstract machines; Sequencing and loop; Programming examples; Refinement; Constructing large software systems; Example of refinement; Appendices; Summary of the most current notations; Syntax; Definitions; Visibility rules; Rules and axioms; Proof obligations.

6 Ainsworth, M, Cruikchank, A H, Wallis, P J L and Groves, L J 'Viewpoint specification and Z' *Information and Software Technology* Vol 36 No 1 pp 43–51 (1994)

7 Alencar, A J and Goguen, J A 'OOZE: an object-oriented Z environment' in America, P (ed) *Proc. ECOOP'91 European Conference on Object-Oriented Programming* Vol 512 of *Lecture Notes in Computer Science* pp 180–199, Springer-Verlag (1991)

8 Ammann, P and Offutt, J 'Functional and test specifications for the Mistix file system'. Technical Report ISSE-TR-93-100, Department of Information & Software Systems Engineering, George Mason University, USA (January 1993)

9 Ammann, P and Offutt, J 'Using formal methods to mechanize category-partition testing'. Technical Report ISSE-TR-93-105, Department of Information & Software Systems Engineering, George Mason University, USA (September 1993)

10 Arnold, D B, Duce, D A and Reynolds, G J 'An approach to the formal specification of configurable models of graphics systems' in Maréchal, G (ed) *Proc. EUROGRAPHICS'87, European Computer Graphics Conference and Exhibition* pp 439–463, Elsevier Science Publishers (North-Holland) (1987)

The paper describes a general framework for the formal specification of modular graphics systems, illustrated by an example taken from the Graphical Kernel System (GKS) standard.

11 Arnold, D B and Reynolds, G J 'Configuring graphics systems components' *IEE/BCS Software Engineering Journal* Vol 3 No 6 pp 248–256 (November 1988)

12 Arthan, R D 'Formal specification of a proof tool' in Prehn and Toetenel[242] pp 356–370

13 Arthan, R D 'On free type definitions in Z' in Nichols[226] pp 40–58

14 Aujila, S, Bryant, A and Semmens, L 'A rigorous review technique: using formal notations within conventional development methods' in *Proc. 1993 Software Engineering Standards Symposium* pp 247–255, IEEE Computer Society Press (1993)

15 Austin, S and Parkin, G I 'Formal methods: a survey'. Technical Report, National Physical Laboratory, Queens Road, Teddington, Middlesex TW11 0LW, UK (March 1993)

16 Bailes, C and Duke, R 'The ecology of class refinement' in Morris and Shaw[212] pp 185–196

17 Bainbridge, J, Whitty, R W and Wordsworth, J B 'Obtaining structural metrics of Z specifications for systems development' in Nicholls[224] pp 269–281

18 Barden, R and Stepney, S 'Support for using Z' in Bowen and Nicholls[44] pp 255–280

19 Barden, R, Stepney, S and Cooper, D 'The use of Z' in Nicholls[226] pp 99–124

20 Barden, R, Stepney, S and Cooper, D *Z in Practice* BCS Practitioner Series, Prentice-Hall (1994)

21 Barrett, G 'Formal methods applied to a floating-point number system' *IEEE Transactions of Software Engineering* Vol 15 No 5 pp 611–621 (May 1989)

This paper presents a formalization of the IEEE standard for binary floating-point arithmetic in Z. The formal specification is refined into four components. The procedures presented form the basis for the floating-point unit of the Inmos IMS T800 transputer. This work resulted in a joint UK Queen's Award for Technological Achievement for Inmos Ltd and the Oxford University Computing Laboratory in 1990. It was estimated that the approach saved a year in development time compared to traditional methods.

22 Barroca, L M and McDermid, J A 'Formal methods: use and relevance for the development of safety-critical systems' *The Computer Journal* Vol 35 No 6 pp 579–599, (December 1992)

23 Baumann, P 'Z and natural semantics' in Bowen and Hall[38] pp 168–184

24 Benjamin, M 'A message passing system: an example of combining CSP and Z' in Nicholls[222] pp 221–228

25 Benveniste, M 'Writing operational semantics in Z: a structural approach' in Prehn and Toetenel[242] pp 164–188

26 Bera, S 'Structuring for the VDM specification language' in Bloomfield *et al*[28] pp 2–25

27 Bjørner, D, Hoare, C A R and Langmaack, H (eds) *VDM and Z—Formal Methods in Software Development* Vol 428 of *Lecture Notes in Computer Science* VDM-Europe, Springer-Verlag (1990)

The 3rd VDM-Europe Symposium was held at Kiel, Germany, 17–21 April 1990. A significant number of papers concerned with Z were presented[61,83,93,114,121,125,170,253,275,298,318].

28 Bloomfield, R, Marshall, L and Jones, R (eds) *VDM—The Way Ahead* Vol 328 of *Lecture Notes in Computer Science* VDM-Europe, Springer-Verlag (1988)

The 2nd VDM-Europe Symposium was held at Dublin, Ireland, 11–16 September 1988. See[3,26].

29 Bowen, J P 'Formal specification and documentation of microprocessor instruction sets' *Microprocessing and Microprogramming* Vol 21 Nos 1–5 pp 223–230 (August 1987)

30 Bowen, J P 'The formal specification of a microprocessor instruction set'. Technical Monograph PRG-60, Oxford University Computing Laboratory, Wolfson Building, Parks Road, Oxford, UK (January 1987)

The Z notation is used to define the Motorola M6800 8-bit microprocessor instruction set.

31 Bowen, J P 'Formal specification of window systems'. Technical Monograph PRG-74, Oxford University Computing Laboratory, Wolfson Building, Parks Road, Oxford, UK (June 1989)

Three existing window systems, X from MIT, WM from Carnegie-Mellon University and the Blit from AT&T Bell Laboratories are covered.

32 Bowen, J P 'POS: Formal specification of a UNIX tool' *IEE/BCS Software Engineering Journal* Vol 4 No 1 pp 67–72 (January 1989)

33 Bowen, J P 'Formal specification of the ProCoS/safemos instruction set' *Microprocessors and Microsystems* Vol 14 No 10 pp 631–643 (December 1990)

This article is part of a special issue on *Formal aspects of microprocessor design*, edited by H S M Zedan. See also[260].

34 Bowen, J P 'X: Why Z?' *Computer Graphics Forum* Vol 11 No 4 pp 221–234 (October 1992)

This paper asks whether window management systems would not be better specified through a formal methodology and gives examples in Z of X11.

35 Bowen, J P 'Formal methods in safety-critical standards' in *Proc. 1993 Software Engineering Standards Symposium* pp 168–177, IEEE Computer Society Press, (1993)

36 Bowen J P, Breuer, P T and Lano, K C 'Formal specifications in software maintenance: from code to Z^{++} and back again' *Information and Software Technology* Vol 35 Nos 11/12 pp 679–690 (November/December 1993)

37 Bowen, J P and Gordon, M J C 'Z and HOL' in Bowen and Hall[38] pp 141–167

38 Bowen, J P and Hall J A (eds) *Z User Workshop, Cambridge 1994*, Workshops in Computing, Springer-Verlag (1994)

Proceedings of the Eighth Annual Z User Meeting, St. John's College, Cambridge, UK. Published in collaboration with the British Computer Society. For individual papers, see[23,37,47,48,51,60,62,87,100,102,113,126,127,129,131,175,194,238,265,301,315,319]. The proceedings also includes an *Introduction and Opening Remarks*, a *Select Z Bibliography*[48] and a section answering *Frequently Asked Questions*[47].

39 Bowen, J P and Hinchey, M G 'Formal methods and safety-critical standards' *IEEE Computer* Vol 27 No 8 pp 68–71 (August 1994)

40 Bowen J P and Hinchey, M G 'Seven more myths of formal methods'. Technical Report PRG-TR-7-94, Oxford University Computing Laboratory, Wolfson Building, Parks Road, Oxford, UK (June 1994) Revised version in *IEEE Software*

This article deals with further myths in addition to those presented in[124].

41 Bowen, J P and Hinchey, M G 'Seven more myths of formal methods: dispelling industrial prejudices' in Naftalin *et al.*[213] pp 105–117

42 Bowen, J P and Hinchey, M G 'Ten commandments of formal methods'. Technical Report 350, University of Cambridge, Computer Laboratory, UK (September 1994). Revised version in *IEEE Computer*

43 Bowen, J P and Hinchey, M G (eds) *ZUM'95—9th International Conference of Z Users, Limerick 1995*. Lecture Notes in Computer Science. Springer-Verlag (1995) (To appear)

44 Bowen, J P and Nicholls, J E (eds) *Z User Workshop, London 1992*. Workshops in Computing. Springer-Verlag (1993)

Proceedings of the Seventh Annual Z User Meeting, DTI Offices, London, UK. Published in collaboration with the British Computer Society. For individual papers, see[18,49,67,71,76,77,90,142,153,172,182,187,195,227,232,244,250,290,297]. The proceedings also include an *Introduction and Opening Remarks*, a *Select Z Bibliography* and a section answering *Frequently Asked Questions*.

45 Bowen, J P and Stavridou, V 'The industrial take-up of formal methods in safety-critical and other areas: a perspective' in Woodcock and Larsen[316] pp 183–195

46 Bowen, J P and Stavridou, V 'Safety-critical systems, formal methods and standards' *IEE/BCS Software Engineering Journal* Vol 8 No 4 pp 189–209 (July 1993)

A survey on the use of formal methods, including B and Z, for safety-critical systems. A previous version is also available as Oxford University Computing Laboratory Technical Report PRG-TR-5-92.

47 Bowen, J P 'Comp.specification.z and Z FORUM frequently asked questions' in Bowen and Hall[38] pp 397–404

48 Bowen, J P 'Select Z bibliography' in Bowen and Hall[38] pp 359–396

49 Bradley, A 'Requirements for Defence Standard 00-55' in Bowen and Nicholls[44] pp 93–94

50 Breuer, P T 'Z! in progress: maintaining Z specifications' in Nicholls[224] pp 295–318

51 Breuer, P T and Bowen, J P 'Towards correct executable semantics for Z' in Bowen and Hall[38] pp 185–209

52 Brien, S M and Nicholls, J E 'Z base standard'. Technical Monograph PRG-107, Oxford University Computing Laboratory, Wolfson Building, Parks Road, Oxford, UK (November 1992). Accepted for standardization under ISO/IEC JTC1/SC22

This is the first publicly available version of the proposed ISO Z Standard. See also[273] for the current most widely available Z reference manual.

53 Brown, D J and Bowen, J P 'The Event Queue: an

extensible input system for UNIX workstations' in *Proc. European Unix Users Group Conference* pp 29–52. EUUG (May 1987)

Available from EUUG Secretariat, Owles Hall, Buntingford, Hertfordshire SG9 9PL, UK.

54 Brownbridge, D 'Using Z to develop a CASE toolset' in Nicholls[222] pp 142–149

55 Bryant, A 'Structured methodologies and formal notations: developing a framework for synthesis and investigation' in Nicholls[222] pp 229–241

56 Butcher, P 'A behavioural semantics for Linda-2' *IEE/BCS Software Engineering Journal* Vol 6 No 4 pp 196–204 (July 1991)

57 Butler, M J 'Service extension at the specification level' in Nicholls[224] pp 319–336

58 Carrington, D 'ZOOM workshop report' in Nicholls[226] pp 352–364

This paper records the activities of a workshop on Z and object-oriented methods held in August 1992 at Oxford. A comprehensive bibliography is included.

59 Carrington, D, Duke, D, Duke, R, King, P, Rose, G A and Smith, G 'Object-Z: an object-oriented extension to Z' in Vuong, S (ed) *Formal Description Techniques, II (FORTE'89)* pp 281–296. Elsevier Science Publishers (North-Holland) (1990)

60 Carrington, D and Stocks, P 'A tale of two paradigms: formal methods and software testing' in Bowen and Hall[38] pp 51–68

Also available as Technical Report 94-4, Department of Computer Science, University of Queensland (1994).

61 Chalin, P and Grogono, P 'Z specification of an object manager' in Bjørner *et al.*[27] pp 41–71

62 Chan, D K C and Trinder, P W 'An object-oriented data model supporting multi-methods, multiple inheritance, and static type checking: a specification in Z' in Bowen and Hall[38] pp 297–315

63 Cohen, B 'Justification of formal methods for system specifications and a rejustification of formal notations' *IEE/BCS Software Engineering Journal* Vol 4 No 1 pp 26–38 (January 1989)

64 Collings, B P, Nicholls, J E and Sørensen, I H 'Introducing formal methods: the CICS experience with Z' in Neumann, B *et al.* (eds) *Mathematical Structures for Software Engineering* Oxford University Press (1991)

65 Coombes, A C and McDermid, J A 'A tool for defining the architecture of Z specifications' in Nicholls[224] pp 77–92

66 Coombes, A C and McDermid, J A 'Specifying temporal requirements for distributed real-time systems in Z'. Computer Science Report YCSA176, University of York, Heslington, York YO1 5DD, UK (1992)

67 Coombes, A C and McDermid, J A 'Using diagrams to give a formal specification of timing constraints in Z' in Bowen and Nicholls[44] pp 119–130

68 Cooper, D 'Educating management in Z' in Nicholls[222] pp 192–194

69 Cordeiro, V A O, Sampaio, A C A and Meira, S L 'From MooZ to Eiffel—a rigorous approach to system development' in Naftalin *et al.*[213] pp 306–325

70 Craig, I *The formal specification of advanced AI architectures* AI Series. Ellis Horwood (September 1991)

This book contains two rather large (and relatively complete) specifications of Artificial Intelligence (AI) systems using Z. The architectures are the blackboard and Cassandra architectures. As well as showing that formal specification *can* be used in AI at the architecture level, the book is intended as a case-studies book, and also contains introductory material on Z (for AI people). The book assumes a knowledge of Z, so for non-AI people its primary use is for the presentation of the large specifications. The blackboard specification, with explanatory text, is around 100 pages.

71 Craigen, D, Gerhart, S L and Ralston, T 'An international survey of industrial applications of formal methods' in Bowen and Nicholls[44] pp 1–5

72 Craigen, D, Gerhart, S L and Ralston, T J 'Formal methods reality check: industrial usage' in Woodcock and Larsen[316] pp 250–267

73 Craigen, D, Gerhart, S L and Ralston, T J 'An international survey of industrial applications of formal methods'. Technical Report NIST GCR 93/626-V1 & 2, Atomic Energy Control Board of Canada, US National Institute of Standards and Technology, and US Naval Research Laboratories (1993)

Volume 1: Purpose, Approach, Analysis and Conclusions; Volume 2: Case Studies. Order numbers: PB93-178556/AS & PB93-178564/AS; National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, USA.

74 Craigen, D, Kromodimoeljo, S, Meisels, I Pase, W and Saaltink, M 'EVES: an overview' in Prehn and Toetenel[242] pp 389–405

75 Cusack, E 'Inheritance in object oriented Z' in America, P (ed) *Proc. ECOOP'91 European Conference on Object-Oriented Programming* Vol 512 of *Lecture Notes in Computer Science* pp 167–179, Springer-Verlag (1991)

76 Cusack, E 'Using Z in communications engineering' in Bowen and Nicholls[44] pp 196–202

77 Cusack, E and Wezeman, C 'Deriving tests for objects specified in Z' in Bowen and Nicholls[44] pp 180–195

78 de Barros, R S M 'Deriving relational database programs from formal specifications' in Naftalin *et al.*[213] pp 703–723

79 de Barros, R S M and Harper, D J 'A method for the specification of relational database applications' in Nicholls[226] pp 261–286

80 Dehbonei, B and Mejia, F 'Formal methods in the railways signalling industry' in Naftalin *et al.*[213] pp 26–34

81 Delisle, N and Garlan, D 'Formally specifying electronic instruments' in *Proc. Fifth International Workshop on Software Specification and Design* IEEE Computer Society (May 1989). Also published in *ACM SIGSOFT Software Engineering Notes* Vol 14 No 3

82 Delisle, N and Garlan, D 'A formal specification of an oscilloscope' *IEEE Software* Vol 7 No 5 29–36 (September 1990)

Unlike most work on the application of formal methods, this research uses formal methods to gain insight into system architecture. The context for this case study is electronic instrument design.

83 Di Giovanni, R and Iachini, P L 'HOOD and Z for the development of complex systems' in Bjørner *et al.*[27] pp 262–289

84 Dick, A J J, Krause, P J and Cozens, J 'Computer aided transformation of Z into Prolog' in Nicholls[222] pp 71–85

85 Diller, A 'Z and Hoare logics' in Nicholls[226] pp 59–76

86 Diller, A *Z: An introduction to formal methods* John Wiley, UK (2nd edn) (1994)

This book offers a comprehensive tutorial to Z from the practical viewpoint. Many natural deduction style proofs are presented and exercises are included. Z as defined in the 2nd edition of *The Z Notation*[273] is used throughout.
Contents: Tutorial introduction; Methods of reasoning; Case studies; Specification animation; Reference manual; Answers to exercises; Glossaries of terms and symbols; Bibliography.

87 Diller, A and Docherty, R 'Z and abstract machine notation: a comparison' in Bowen and Hall[38] pp 250–263

88 Dix, A J, Finlay, J, Abowd, G D and Beale, R *Human–computer interaction* Prentice-Hall International (1993)

89 Doma, V and Nicholl, R 'EZ: a system for automatic prototyping of Z specifications' in Prehn and Toetenel[242] pp 189–203

90 Draper, C 'Practical experiences of Z and SSADM' in Bowen and Nicholls[44] pp 240–251

91 Duce, D A, Duke, D J, ten Hagen, P J W and Reynolds, G J 'PREMO—an initial approach to a formal definition' *Computer Graphics Forum* Vol 13 No 3 C-393--C-406 (1994)

PREMO (Presentation Environments for Multimedia Objects) is a work item proposal by the ISO/IEC JTC11/SC24 committee, which is responsible for international standardization in the area of computer graphics and image processing.

92 Duke, D 'Enhancing the structures of Z specifications' in Nicholls[226] pp 329–351

93 Duke, D and Duke, R 'Towards a semantics for Object-Z' in Bjørner *et al.*[27] pp 244–261

94 Duke, R and Duke, D 'Aspects of object-oriented formal specification' in *Proc. 5th Australian Software Engineering Conference (ASWEC'90)* pp 21–26 (1990)

95 Duke, R, Hayes, I J, King, P and Rose, G A 'Protocol specification and verification using Z' in Aggarwal, S and Sabnani, K (eds) *Protocol specification, testing, and verification VIII* pp 33–46, Elsevier Science Publishers (North-Holland) (1988)

96 Duke, R, King, P, Rose, G A and Smith, G 'The Object-Z specification language' in Korson, T, Vaishnavi, V and Meyer, B (eds) *Technology of object-oriented languages and systems: TOOLS 5* pp 465–483, Prentice-Hall (1991)

97 Duke, R, King, P, Rose, G A and Smith, G 'The Object-Z specification language: Version 1'. Technical Report 91-1, Department of Computer Science, University of Queensland, St Lucia 4072, Australia (April 1991)

The most complete (and currently the standard) reference on Object-Z. It has been reprinted by ISO JTCI WG7 as document number 372. A condensed version of this report was published as[96].

98 Duke, R, Rose, G A and Lee, A 'Object-oriented protocol specification' in Logrippo, L, Probert, R L and Ural, H (eds) *Protocol specification, testing, and verification X* pp 325–338. Elsevier Science Publishers (North-Holland) (1990)

99 Duke, R and Smith, G 'Temporal logic and Z specifications' *Australian Computer Journal* Vol 21 No 2 pp 62–69 (May 1989)

100 Engel, M 'Specifying real-time systems with Z and the Duration Calculus' in Bowen and Hall[38] pp 282–294

101 Evans, A S 'Specifying and verifying concurrent systems using Z' in Naftalin *et al.*[213] pp 366–400

102 Evans, A S 'Visualizing concurrent Z specifications' in Bowen and Hall[38] pp 269–281

103 Fencott, P C, Galloway, A J, Lockyer, M A, O'Brien, S J and Pearson, S 'Formalizing the semantics of Ward/Mellor SA/RT essential models using a process algebra' in Naftalin *et al.*[213] pp 681–702

104 Fenton, N E and Mole, D 'A note on the use of Z for flowgraph transformation' *Information and Software Technology* Vol 30 No 7 pp 432–437 (1988)

105 Fergus, E and Ince, D C 'Z specifications and modal logic' in Hall, P A V (ed) *Proc. Software Engineering 90* Vol 1 of *British Computer Society Conference Series*, Cambridge University Press (1990)

106 Fidge, C J 'Specification and verification of real-time behaviour using Z and RTL' in Vytopil, J (ed) *Formal techniques in real-time and fault-tolerant systems*. Lecture Notes in Computer Science pp 393–410. Springer-Verlag (1992)

107 Fidge, C J 'Real-time refinement' in Woodcock and Larsen[316] pp 314–331

108 Fidge, C J 'Adding real-time to formal program development' in Naftalin *et al.*[213] pp 618–638

109 Fidge, C J 'Proof obligations for real-time refinement' in Till[292] pp 279–305

110 Flynn, M, Hoverd, T and Brazier, D 'Formalizer—an interactive support tool for Z' in Nicholls[222] pp 128–141

111 Fuchs, N E 'Specifications are (preferably) executable' *IEE/BCS Software Engineering Journal* Vol 7 No 5 pp 323–334 (September 1992)

112 Gardiner, P H B, Lupton, P J and Woodcock, J C P 'A simpler semantics for Z' in Nicholls[224] pp 3–11.

113 Garlan, D 'Integrating formal methods into a professional master of software engineering program' in Bowen and Hall[38] pp 71–85

114 Garlan, D and Delisle, N 'Formal specifications as reusable frameworks' in Bjørner *et al.*[27] pp 150–163

115 Garlan, D and Notkin, D 'Formalizing design spaces: implicit invocation mechanisms' in Prehn and Toetenel[242] pp 31–45

116 Gerhart, S L 'Applications of formal methods: developing virtuoso software' *IEEE Software* Vol 7 No 5 pp 6–10 (September 1990)

This is an introduction to a special issue on Formal Methods with an emphasis on Z in particular. It was published in conjunction with special Formal Methods issues of *IEEE Transactions of Software Engineering and IEEE Computer*. See also[82,124,214,271,305].

117 Gerhart, S L, Craigen, D and Ralston, T 'Observations on industrial practice using formal methods' in *Proc. 15th International Conference on Software Engineering (ICSE), Baltimore, Maryland, USA* (May 1993)

118 Gerhart, S L, Craigen, D and Ralston, T 'Experience with formal methods in critical systems' *IEEE Software* Vol 11 No 1 pp 21–28 (January 1994)

Several commercial and exploratory cases in which Z features heavily are briefly presented on p 24. See also[173].

119 Gilmore, S 'Correctness-oriented approaches to software development'. Technical Report ECS-LFCS-91-147

(also CST-76-91), Department of Computer Science, University of Edinburgh, Edinburgh EH9 3JZ, UK (1991)

This PhD thesis provides a critical evaluation of Z, VDM and algebraic specifications.

120 Goodman, H S 'Animating Z specifications in Haskell using a monad'. Technical Report CSR-93-10, School of Computer Science, University of Birmingham, Birmingham B15 2TT, UK (November 1993)

121 Gotzhein, R 'Specifying open distributed systems with Z' in Bjørner *et al.*[27] pp 319–339

122 Gravell, A M 'Minimization in formal specification and design', in Nicholls[222] pp 32–45

123 Gravell, A M 'What is a good formal specification?' in Nicholls[224] pp 137–150

124 Hall, J A 'Seven myths of formal methods' *IEEE Software* Vol 7 No 5 pp 11–19 (September 1990)

Formal methods are difficult, expensive, and not widely useful, detractors say. Using a case study and other real-world examples, this article challenges such common myths.

125 Hall, J A 'Using Z as a specification calculus for object-oriented systems' in Bjørner *et al.*[27] pp 290–318

126 Hall, J A 'Specifying and interpreting class hierarchies in Z' in Bowen and Hall[38] pp 120–138

127 Hall, J G and McDermid, J A 'Towards a Z method: axiomatic specification in Z' in Bowen and Hall[38] pp 213–229

128 Hall, P A V 'Towards testing with respect to formal specification' in *Proc. Second IEE/BCS Conference on Software Engineering* No 290 in Conference Publication, pp 159–163. IEE/BCS (July 1988)

129 Hammond, J A R 'Producing Z specifications from object-oriented analysis' in Bowen and Hall[38] pp 316–336

130 Harrison, M D 'Engineering human-error tolerant software' in Nicholls[226] pp 191–204

131 Hasselbring, W 'Animation of Object-Z specifications with a set-oriented prototyping language' in Bowen and Hall[38] pp 337–356

132 Haughton, H P 'Using Z to model and analyse safety and liveness properties of communication protocols' *Information and Software Technology* Vol 33 No 8 pp 575–580 (October 1991)

133 Hayes, I J 'Specification directed module testing' *IEEE Transactions on Software Engineering* Vol 12 No 1 pp 124–133 (January 1986)

134 Hayes, I J 'A generalization of bags in Z' in Nicholls[222] pp 113–127

135 Hayes, I J 'Specifying physical limitations: a case study of an oscilloscope'. Technical Report 167, Department of Computer Science, University of Queensland, St Lucia 4072, Australia (July 1990)

136 Hayes, I J 'Interpretations of Z schema operators' in Nicholls[224] pp 12–26

137 Hayes, I J 'Multi-relations in Z: a cross between multi-sets and binary relations' *Acta Informatica* Vol 29 No 1 pp 33–62 (February 1992)

138 Hayes, I J 'VDM and Z: a comparative case study' *Formal Aspects of Computing* Vol 4 No 1 pp 76–99 (1992)

139 Hayes, I J (ed) *Specification case studies* Prentice-Hall International Series in Computer Science (2nd edn) (1993)

This is a revised edition of the first ever book on Z, originally published in 1987; it contains substantial changes to every chapter. The notation has been revised to be consistent with *The Z Notation: A Reference Manual* by Mike Spivey[273]. The CAVIAR chapter has been extensively changed to make use of a form of modularization. Divided into four sections, the first provides tutorial examples of specifications, the second is devoted to the area of software engineering, the third covers distributed computing, analysing the role of mathematical specification, and the fourth part covers the IBM CICS transaction processing system. Appendices include comprehensive glossaries of the Z mathematical and schema notation. The book will be of interest to the professional software engineer involved in designing and specifying large software projects. The other contributors are W Flinn, R B Gimson, S King, C C Morgan, I H Sørensen and B A Sufrin.

140 Hayes, I J and Jones, C B 'Specifications are not (necessarily) executable' *IEE/BCS Software Engineering Journal* Vol 4 No 6 pp 330–338 (November 1989)

141 Hayes, I J, Jones, C B and Nicholls, J E 'Understanding the differences between VDM and Z' *FACS Europe* Series I Vol 1 No 1 pp 7–30 (Autumn 1993)

Also available as Technical Report UMCS-93-8-1, Department of Computer Science, University of Manchester, UK (1993).

142 Hayes, I J and Wildman, L 'Towards libraries for Z' in Bowen and Nicholls[44] pp 9–36

143 He Jifeng, Hoare, C A R, Fränzle, M, Müller-Ulm, M, Olderog, E-R, Schenke, M, Ravn, A P and Rischel, H 'Provably correct systems' in Langmaack, H, de Roever, W-P and Vytopil, J (eds) *Formal techniques in real time and fault tolerant systems* Vol 863 of *Lecture Notes in Computer Science* pp 288–335. Springer-Verlag (1994)

144 He Jifeng, Hoare, C A R and Sanders, J W 'Data refinement refined' in Robinet, B and Wilhelm, R (eds) *Proc. ESOP 86* Vol 213 of *Lecture Notes in Computer Science* pp 187–196. Springer-Verlag (1986)

145 Hepworth, B 'ZIP: A unification initiative for Z standards, methods and tools' in Nicholls[222] pp 253–259

146 Hepworth, B and Simpson, D 'The ZIP project' in Nicholls[224] pp 129–133

147 Houston, I S C and King, S 'CICS project report: experiences and results from the use of Z in IBM' in Prehn and Toetenel[242] pp 588–596

148 Iachini, P L 'Operation schema iterations' in Nicholls[224] pp 50–57

149 Imperato, M *An Introduction to Z* Chartwell-Bratt (1991)

Contents: Introduction; Set theory; Logic; Building Z specifications; Relations; Functions; Sequences; Bags; Advanced Z; Case study; a simple banking system.

150 Ince, D C *An introduction to discrete mathematics, formal system specification and Z* Oxford Applied Mathematics and Computing Science Series. Oxford University Press (2nd edn) (1993)

151 Jackson, D 'Abstract model checking of infinite specifications' in Naftalin *et al.*[213] pp 519–531

152 Jacky, J 'Formal specifications for a clinical cyclotron control system' *ACM SIGSOFT Software Engineering Notes* Vol 15 No 4 pp 45–54 (September 1990)

153 Jacky, J 'Formal specification and development of control system input/output' in Bowen and Nicholls[44] pp 95–108

154 Jacky, J 'Specifying a safety-critical control system in Z' in Woodcock and Larsen[316] pp 388–402

155 Jacob, J 'The varieties of refinements' in Morris and Shaw[212] pp 441–455

156 Johnson, C W 'Applying temporal logic to support the specification and prototyping of concurrent multi-user interfaces' in Diaper, D and Hammond, N (eds) *People and computers VI: usability now* pp 145–156, Cambridge University Press (1991)

157 Johnson, C W and Harrison, M D 'Declarative graphics and dynamic interaction' in Post, F H and Barth, W (eds) *Proc. EUROGRAPHICS'91* pp 195–207, Elsevier Science Publications (North-Holland) (1991)

158 Johnson, M and Sanders, P 'From Z specifications to functional implementations' in Nicholls[222] pp 86–112

159 Jones, C B 'Interference revisited' in Nicholls[224] pp 58–73

160 Jones, C B, Shaw, R C and Denvir, T (eds) *5th Refinement Workshop*. Workshop in Computing, Springer-Verlag (1992)

The workshop was held at *Lloyd's Register*, London, UK, 8–10 January 1992. See[259].

161 Jones, R B 'ICL ProofPower' *BCS FACS FACTS*, Series III Vol 1 No 1 pp 10–13 (Winter 1992)

162 Jordan, D, McDermid, J A and Toyn, I 'CADiZ—computer aided design in Z' in Nicholls[224] pp 93–104

163 Josephs, M B 'The data refinement calculator for Z specifications' *Information Processing Letters* Vol 27 No 1 pp 29–33 (1988)

164 Josephs, M B 'A state-based approach to communicating processes' *Distributed Computing* Vol 3 pp 9–18 (1988)

A theoretical paper on combining features of CSP and Z.

165 Josephs, M B 'Specifying reactive systems in Z'. Technical Report PRG-TR-19-91, Oxford University Computing Laboratory, Wolfson Building, Parks Road, Oxford, UK (July 1991)

166 Josephs, M B and Redmond-Pyle, D 'Entity-relationship models expressed in Z: a synthesis of structured and formal methods'. Technical Report PRG-TR-20-91, Oxford University Computing Laboratory, Wolfson Building, Parks Road, Oxford, UK (July 1991)

167 Kemp, D H 'Specification of Viper 1 in Z'. Memorandum No. 4195, RSRE, Ministry of Defence, Malvern, Worcestershire, UK (October 1988)

168 Kemp, D H 'Specification of Viper 2 in Z'. Memorandum No. 4217, RSRE, Ministry of Defence, Malvern, Worcestershire, UK (October 1988)

169 King, P 'Printing Z and Object-Z LaTeX documents'. Department of Computer Science, University of Queensland (May 1990)

A description of a Z style option 'oz.sty', an extended version of Mike Spivey's 'zed.sty'[270], for use with the LaTeX document preparation system[174]. It is particularly useful for printing Object-Z documents[59,93].

170 King, S 'Z and the refinement calculus' in Bjørner *et al.*[27] pp 164–188

Also published as Technical Monograph PRG-79, Oxford University Computing Laboratory (February 1990)

171 King, S and Sørensen, I H 'Specification and design of a library system' in McDermid[200]

172 Knight, J C and Kienzle, D M 'Preliminary experience using Z to specify a safety-critical system' in Bowen and Nicholls[44] pp 109–118

173 Knight, J C and Littlewood, B 'Critical task of writing dependable software' *IEEE Software* Vol 11 No 1 pp 16–20 (January 1994)

Guest editors' introduction to a special issue of *IEEE Software on Safety-Critical Systems*. A short section on formal methods mentions several Z books on page 18. See also[118].

174 Lamport, L *LaTeX User's Guide & Reference Manual* Addison-Wesley, USA (1986)

Z specifications may be produced using the document preparation system LaTeX together with a special LaTeX style option. The most widely used style files are fuzz.sty[272], zed.sty[270] and oz.sty[169]

175 Lamport, L 'TLZ' in Bowen and Hall[38] pp 267–268. Abstract

176 Lano, K C 'Z^{++}, an object-orientated extension to Z' in Nicholls[224] pp 151–172

177 Lano, K C 'Refinement in object-oriented specification languages' in Till[292] pp 236–259

178 Lano, K C and Breuer, P T 'From programs to Z specifications' in Nicholls[222] pp 46–70

179 Lano, K C and Haughton, H P 'An algebraic semantics for the specification language Z^{++}' in *Proc. Algebraic Methodology and Software Technology Conference (AMAST '91)* Springer-Verlag (1992)

180 Lano, K C and Haughton, H P 'Reasoning and refinement in object-oriented specification languages' in Madsen, O L (ed) *ECOOP'92: European Conference on Object-Oriented Programming* Vol 615 of *Lecture Notes in Computer Science* pp 78–97, Springer-Verlag (1992)

181 Lano, K C and Haughton, H P (eds) *Object Oriented Specification Case Studies*. Object Oriented Series. Prentice-Hall International (1993)

Contents: Chapters introducing object-oriented methods, object-oriented formal specification and the links between formal and structured object-oriented techniques; seven case studies in particular object-oriented formal methods, including: The Unix filing system: a MooZ specification; An Object-Z specification of a mobile phone system; Object-oriented specification in VDM^{++}; Specifying a concept-recognition system in Z^{++}; Specification in OOZE; Refinement in Fresco; Small VDM: an environment for formal specification and prototyping in Smalltalk. A glossary, index and bibliography are also included. The contributors are some of the leading figures in the area, including the developers of the above methods and languages: Silvio Meira, Gordon Rose, Roger Duke, Antonio Alencar, Joseph Goguen, Alan Wills, Cassio Souza dos Santos, Ana Cavalcanti.

182 Lano, K C and Haughton, H P 'Reuse and adaptation of Z specifications' in Bowen and Nicholls[44] pp 62–90

183 Lightfoot, D *Formal specification using Z* Macmillan (1991)

Contents: Introduction; Sets in Z; Using sets to describe a system—a simple example; Logic: propositional calculus; Example of a Z specification document; Logic: predicate calculus; Relations; Functions; A seat allocation system; Sequences; An example of sequences—the aircraft example again; Extending a specification; Collected notation; Books on formal specification; Hints on creating specifications; Solutions to exercises. Also available in French

184 Lindsay, P A 'Reasoning about Z specifications: a VDM perspective'. Technical Report 93-20, Department of Computer Science, University of Queensland, St Lucia 4072, Australia (October 1993)

185 Lindsay, P A 'On transferring VDM verification techniques to Z' in Naftalin *et al.*[213] pp 190–213

Also available as Technical Report 94-10, Department of Computer Science, University of Queensland (1994)

186 Lindsay, P A and van Keulen, E 'Case studies in the verification of specifications in VDM and Z'. Technical Report 94-3, Department of Computer Science, University of Queensland, St Lucia 4072, Australia (March 1994)

187 Love, M 'Animating Z specifications in SQL*Forms 3.0' in Bowen and Nicholls[44] pp 294–306

188 Lupton, P J 'Promoting forward simulation' in Nicholls[224] pp 27–49

189 Macdonald, R 'Z usage and abusage'. Report No. 91003, RSRE, Ministry of Defence, Malvern, Worcestershire, UK (February 1991)

This paper presents a miscellany of observations drawn from experience of using Z, shows a variety of techniques for expressing certain classes of idea concisely and clearly, and alerts the reader to certain pitfalls which may trap the unwary.

190 Mahony, B P and Hayes, I J 'A case-study in timed refinement: a central heater' in Morris and Shaw[212] pp 138–149

191 Mahony, B P and Hayes, I J 'A case-study in timed refinement: a mine pump' *IEEE Transactions on Software Engineering* Vol 18 No 9 pp 817–826 (September 1992)

192 Mahony, B P, Millerchip, C and Hayes, I J 'A boiler control system: a case-study in timed refinement'. Technical Report, Department of Computer Science, University of Queensland, St Lucia 4072, Australia (23 June 1993)

A specification and top-level design of a steam generating boiler system is presented as an example of the formal development of a real-time system.

193 Martin, A 'Encoding W: a logic for Z in 2OBJ' in Woodcock and Larsen[316] pp 462–481

194 Mataga, P and Zave, P 'Formal specification of telephone features' in Bowen and Hall[38] pp 29–50

195 Maung, I and Howse, J R 'Introducing Hyper-Z—a new approach to object orientation in Z' in Bowen and Nicholls[44] pp 149–165

196 May, M D 'Use of formal methods by a silicon manufacturer' in Hoare, C A R (ed) *Developments in concurrency and communication* University of Texas at Austin Year of Programming Series, Chapter 4, pp 107–129, Addison-Wesley (1990)

197 May, M D, Barrett, G and Shepherd, D E 'Designing chips that work' in Hoare CAR and Gordon M J C (eds) *Mechanized reasoning and hardware design* pp 3–19, Prentice-Hall International Series in Computer Science (1992)

198 May, M D and Shepherd, D E 'Verification of the IMS T800 microprocessor' in *Proc. Electronic Design Automation* pp 605–615, London, UK (September 1987)

199 McDermid, J A 'Special section on Z' *IEE/BCS Software Engineering Journal* Vol 4 No 1 pp 25–72 (January 1989)

A special issue on Z, introduced and edited by Prof. J A McDermid. See also[32,63,269,311].

200 McDermid, J A (ed) *The theory and practice of refinement: approaches to the formal development of large-scale software systems* Butterworth Scientific (1989)

This book contains papers from the 1st Refinement Workshop held at the University of York, UK, 7-8 January 1988. Z-related papers include[171,218].

201 McDermid, J A 'Formal methods: use and relevance for the development of safety critical systems' in Bennett, P A (ed) *Safety aspects of computer control* Butterworth-Heinemann, Oxford, UK (1993)

202 McMorran, M A and Powell, S *Z Guide for Beginners* Blackwell Scientific (1993)

203 Meira, S L and Cavalcanti, A L C 'Modular object-oriented Z specifications' in Nicholls[224] pp 173–192

204 Meyer, B 'On formalism in specifications' *IEEE Software* Vol 2 No 1 pp 6–26 (January 1985)

205 Moffett, J D and Sloman, M S 'A case study representing a model: to Z or not to Z? 'in Nicholls[224] pp 254–268

206 Monahan, B Q and Shaw, R C 'Model-based specifications' in McDermid, J A (ed) *Software engineer's reference book*, Chapter 21, Butterworth-Heinemann, Oxford, UK (1991)

This chapter contains a case study in Z, followed by a discussion of the respective trade-offs in specification between Z and VDM.

207 Morgan, C C *Programming from specifications* Prentice-Hall International Series in Computer Science (2nd edn) (1994)

This book presents a rigorous treatment of most elementary program development techniques, including iteration, recursion, procedures, parameters, modules and data refinement.

208 Morgan, C C and Sanders, J W 'Laws of the logical calculi'. Technical Monograph PRG-78, Oxford University Computing Laboratory, Wolfson Building, Parks Road, Oxford, UK (September 1989)

This document records some important laws of classical predicate logic. It is designed as a reservoir to be tapped by *users* of logic, in system development.

209 Morgan, C C and Sufrin, B A 'Specification of the Unix filing system' *IEEE Transactions on Software Engineering* Vol 10 No 2 pp 128–142 (March 1984)

210 Morgan, C C and Vickers, T (eds) *On the refinement calculus*. Formal Approaches to Computing and Information Technology series (FACIT). Springer-Verlag (1994)

This book collects together the work accomplished at Oxford on the refinement calculus: the rigorous development, from state-based assertional specification, of executable imperative code.

211 Morgan, C C and Woodcock, J C P (eds) *3rd Refinement Workshop*. Workshops in Computing, Springer-Verlag (1991)

The workshop was held at the IBM Laboratories, Hursley Park, UK, 9-11 January 1990. See[258]

212 Morris, J M and Shaw, R C (eds) *4th Refinement Workshop*. Workshops in Computing, Springer-Verlag (1991)

The workshop was held at Cambridge, UK, 9-11 January 1991. For Z related papers, see[16,155,190,304,307,312]

213 Naftalin, M, Denvir, T and Bertran, M (eds) *FME'94: Industrial benefit of formal methods* Vol 873 of *Lecture Notes in Computer Science*. Formal Methods Europe, Springer-Verlag (1994)

The 2nd FME Symposium was held at Barcelona, Spain, 24–28 October 1994. Z-related papers include[41,69,78,101,103,108,151,185]. B-related papers include[80,249,285].

214 Narayana, K T and Dharap, S 'Formal specification of a look manager' *IEEE Transactions of Software Engineering* Vol 16 No 9 pp 1089–1103 (September 1990)

A formal specification of the look manager of a dialog system is presented in Z. This deals with the presentation of visual aspects of objects and the editing of those visual aspects.

215 Narayana, K T and Dharap, S 'Invariant properties in a dialog system' *ACM SIGSOFT Software Engineering Notes* Vol 15 No 4 pp 67–79 (September 1990)

216 Nash, T C 'Using Z to describe large systems' in Nicholls[222] pp 150–178

217 Nehlig, Ph W and Duce, D A 'GKS-9x: the design output primitive, an approach to specification' *Computer Graphics Forum* Vol 13 No 3 pp, C-381-C-392 (1994)

218 Neilson, D S 'Hierarchical refinement of a Z specification' in McDermid[200]

219 Neilson, D S 'From Z to C: illustration of a rigorous development method'

Technical Monograph PRG-101, Oxford University Computing Laboratory, Wolfson Building, Parks Road, Oxford, UK (1990)

220 Neilson, D S 'Machine support for Z: the zedB tool' in Nicholls[224] pp 105–128

221 Neilson, D S and Prasad, D 'zedB: a proof tool for Z built on B' in Nicholls[226] pp 243–258

222 Nicholls, J E (ed) *Z User Workshop, Oxford 1989.* Workshops in Computing. Springer-Verlag (1990)

Proceedings of the Fourth Annual Z User Meeting, Wolfson College & Rewley House, Oxford, UK, 14–15 December 1989. Published in collaboration with the British Computer Society. For the opening address see[233]. For individual papers, see[24,54,55,68,84,110,122,134,145,158,178,216,235,262,274,302].

223 Nicholls, J E 'A survey of Z courses in the UK' in *Z User Workshop, Oxford 1990*[224] pp 343–350

224 Nicholls, J E (ed) *Z User Workshop, Oxford 1990).* Workshops in Computing. Springer-Verlag (1991)

Proceedings of the Fifth Annual Z User Meeting, Lady Margaret Hall, Oxford, UK, 17–18 December 1990. Published in collaboration with the British Computer Society. For individual papers, see[17,50,57,65,112,123,136,146,148,159,162,176,203,205,220,223,230,245,256,303,320]. The proceedings also include an *Introduction and Opening Remarks*, a *Selected Z Bibliography*, a selection of posters, and information on Z tools.

225 Nicholls, J E 'Domains of application for formal methods' in *Z User Workshop, York 1991*[226] pp 145–156

226 Nicholls, J E (ed) *Z User Workshop, York 1991.* Workshops in Computing. Springer-Verlag (1992)

Proceedings of the Sixth Annual Z User Meeting, York, UK. Published in collaboration with the British Computer Society. For individual papers, see[13,19,79,58,85,92,130,221,225,239,251,263,291,296,314,324].

227 Nicholls, J E 'Plain guide to the Z base standard' in Bowen and Nicholls[44] pp 52–61

228 Nix, C J and Collings, B P 'The use of software engineering, including the Z notation, in the development of CICS' *Quality Assurance* Vol 14 No 3 pp 103–110 (September 1988)

229 Norcliffe, A and Slater, G *Mathematics for software construction.* Series in Mathematics and its Applications. Ellis Horwood (1991)

Contents: Why mathematics; Getting started: sets and logic; Developing ideas: schemas; Functions; Functions in action; A real problem from start to finish: a drinks machine; Sequences; Relations; Generating programs from specifications: refinement; The role of proof; More examples of specifications; Concluding remarks; Answers to exercises.

230 Norcliffe, A and Valentine, S H 'A video-based training course in reading Z specifications' in Nicholls[224] pp 337–342

231 Norcliffe, A and Valentine, S H 'Z readers video course'. PAVIC Publications (1992). Sheffield Hallam University, 33 Collegiate Crescent, Sheffield S10 2BP, UK

Video-based Training Course on the Z Specification Language. The course consists of five videos, each of approximately one hour duration, together with supporting texts and case studies.

232 Normington, G 'Cleanroom and Z', in Bowen and Nicholls[44] pp 281–293

233 Oakley, B 'The state of use of formal methods' in Nicholls[222] pp 1–5

A record of the opening address at ZUM'89.

234 Parker, C E 'Z tools catalogue'. ZIP project report ZIP/BAe/90/020, British Aerospace, Software Technology Department, Warton PR4 1AX, UK (May 1991)

235 Phillips, M 'CICS/ESA 3.1 experiences' in Nicholls[222] pp 179–185

Z was used to specify 37 000 lines out of 268 000 lines of code in the IBM CICS/ESA 3.1 release. The initial development benefit from using Z was assessed as being a 9% improvement in the *total development cost* of the release, based on the reduction of programmer days fixing problems.

236 Pilling, M, Burns, A and Raymond, K 'Formal specifications and proofs of inheritance protocols for real-time scheduling' *IEE/BCS Software Engineering Journal* Vol 5 No 5 pp 263–279 (September 1990)

237 Place, P R H and Kang, K C 'Safety-critical software: status report and annotated bibliography'. Technical Report CMU/SEI-92-TR-5 & ESC-TR-93-182, Software Engineering Institute, Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213, USA (June 1993)

238 Polack, F and Mander, K C 'Software quality assurance using the SAZ method' in Bowen and Hall[38] pp 230–249

239 Polack, F, Whiston, M and Hitchcock, P 'Structured analysis—a draft method for writing Z specifications' in Nicholls[226] pp 261–286

240 Polack, F, Whiston, M and Mander, K C 'The SAZ project: integrating SSADM and Z' in Woodcock and Larsen[316] pp 541–557

241 Potter, B F, Sinclair, J E and Till, D *An introduction to formal specification and Z.* Prentice-Hall International Series in Computer Science (1991)

Contents: Formal specification in the context of software engineering; An informal introduction to logic and set theory; A first specification; The Z notation: the mathematical language, relations and functions, schemas and specification structure; A first specification revisited; Formal reasoning; From specification to program: data and operation refinement, operation decomposition; From theory to practice.

242 Prehn, S and Toetenel, W J (eds) *VDM'91: Formal Software Development Methods* Vol 551 of *Lecture Notes in Computer Science* Springer-Verlag (1991). Vol 1: Conference Contributions

The 4th VDM-Europe Symposium was held at Noordwijkerhout, The Netherlands, 21–25 October 1991. Papers with relevance to Z include[12,25,74,89,115,147,267,299,306,323]. See also[243].

243 Prehn, S and Toetenel, W J (eds) *VDM'91: Formal Software Development Methods* Vol 552 of *Lecture Notes in Computer Science* Springer-Verlag (1991) Vol 2: Tutorials

Papers with relevance to Z include[4,313]. See also[242].

244 Rafsanjani, G-H B and Colwill, S J 'From Object-Z to C++: a structural mapping' in Bowen and Nicholls[44] pp 166–179

245 Randell, G P 'Data flow diagrams and Z' in Nicholls[224] pp 216–227

246 Randell, G P 'Improving the translation from data flow diagrams into Z by incorporating the data dictionary'. Report No. 92004, RSRE, Ministry of Defence, Malvern, Worcestershire, UK (January 1992)

247 Ratcliff, B *Introducing specification using Z: a practical case study approach* International Series in Software Engineering, McGraw-Hill (1994)

248 Reizer, N R, Abowd, G D, Meyers, B C and Place, P R H 'Using formal methods for requirements specification of a proposed POSIX standard' in *IEEE International Conference on Requirements Engineering (ICRE'94)* (April 1994)

249 Ritchie, B, Bicarregui, J and Haughton, H P 'Experiences in using the abstract machine notation in a GKS case study' in Naftalin *et al.*[213] pp 93–104

250 Ruddle, A R 'Formal methods in the specification of real-time, safety-critical control systems' in Bowen and Nicholls[44] pp 131–146

251 Saaltink, M 'Z and Eves' in Nicholls[226] pp 223–242

252 Saiedian, H 'The mathematics of computing' *Journal of Computer Science Education* Vol 3 No 3 pp 203–221 (1992)

253 Sampaio, A C A and Meira, S L 'Modular extensions to Z' in Bjørner *et al.*[27] pp 211–232

254 Schuman, S A and Pitt, D H 'Object-oriented subsystem specification' Meertens, L (ed) *Program specification and transformation* pp 313–341, Elsevier Science Publishers (North-Holland) (1987)

255 Schuman, S A, Pitt, D H and Byers, P J 'Object-oriented process specification' in Rattray, C (ed) *Specification and verification of concurrent systems.* Workshops in Computing, pp 21–70. Springer-Verlag (1990)

256 Semmens, L T and Allen, P M 'Using Yourdon and Z: an approach to formal specification' in Nicholls[224] pp 228–253

257 Semmens, L T, France, R B and Docker, T W G 'Integrated structured analysis and formal specification techniques' *The Computer Journal* Vol 35 No 6 pp 600–610 (December 1992)

258 Sennett, C T 'Using refinement to convince: lessons learned from a case study' in Morgan and Woodcock[211] pp 172–197

259 Sennett, C T 'Demonstrating the compliance of Ada programs with Z specifications' in Jones *et al.*[160]

260 Shepherd, D E 'Verified microcode design' *Microprocessors and Microsystems* Vol 14 No 10 pp 623–630 (December 1990)

This article is part of a special issue of *Formal aspects of microprocessor design*, edited by H S M Zedan. See also[33].

261 Shepherd, D E and Wilson, G 'Making chips that work' *New Scientist*, 1664 pp 61–64 (May 1989)

A general article containing information on the formal development of the T800 floating-point unit for the transputer including the use of Z.

262 Smith, A 'The Knuth-Bendix completion algorithm and its specification in Z' in Nicholls[222] pp 195–220

263 Smith, A 'On recursive free types in Z' in Nicholls[226] pp 3–39

264 Smith, G *An object-oriented approach to formal specification* PhD thesis, Department of Computer Science, University of Queensland, St Lucia 4072, Australia (October 1992)

A detailed description of a version of Object-Z similar to (but not identical to) that in[97]. The thesis also includes a formalization of temporal logic history invariants and a fully abstract model of classes in Object-Z.

265 Smith, G 'An object-oriented development framework for Z' in Bowen and Hall[38] pp 89–107

266 Smith, G and Duke, R 'Modelling a cache coherence protocol using Object-Z' in *Proc. 13th Australian Computer Science Conference (ACSC-13)* pp 352–361 (1990)

267 Smith, P and Keighley, R 'The formal development of a secure transaction mechanism' in Prehn and Toetenel[242] pp 457–476

268 Spivey, J M *Understanding Z: a specification language and its formal semantics* Vol 3 of *Cambridge Tracts in Theoretical Computer Science* Cambridge University Press (January 1988)

Published version of 1985 DPhil thesis.

269 Spivey, J M 'An introduction to Z and formal specifications' *IEE/BCS Software Engineering Journal* Vol 4 No 1 pp 40–50 (January 1989)

270 Spivey, J M 'A guide to the zed style option' Oxford University Computing Laboratory (December 1990)

A description of the Z style option 'zed.sty' for use with the LaTeX document preparation system[174].

271 Spivey, J M 'Specifying a real-time kernel' *IEEE Software* Vol 7 No 5 pp 21–28 (September 1990)

This case study of an embedded real-time kernel shows that mathematical techniques have an important role to play in documenting systems and avoiding design flaws.

272 Spivey, J M *The fUZZ Manual* Computing Science Consultancy, 34 Westlands Grove, Stockton Lane, York YO3 0EF, UK (2nd edn) (July 1992)

The manual describes a Z type-checker and 'fuzz.sty' style option for LaTeX documents[174]. The package is compatible with the book, *The Z Notation: A Reference Manual* by the same author[273].

273 Spivey, J M *The Z Notation: A Reference Manual.* Prentice-Hall International Series in Computer Science (2nd edn) (1992)

This is a revised edition of the first widely available reference manual on Z originally published in 1989. The book provides a complete and definitive guide to the use of Z in specifying information systems, writing specifications and designing implementations. See also the draft Z standard[52].
Contents: Tutorial introduction; Background; The Z language; The mathematical tool-kit; Sequential systems; Syntax summary; Changes from the first edition; Glossary.

274 Spivey, J M and Sufrin, B A 'Type inference in Z' in Nicholls[222] pp 6–31

Also published as[275].

275 Spivey, J M and Sufrin, B A 'Type inference in Z' in Bjørner *et al.*[27] pp 426–438

276 Stepney, S *High integrity compilation: a case study* Prentice-Hall (1993)

277 Stepney, S and Barden, R 'Annotated Z bibliography' *Bulletin of the European Association of Theoretical Computer Science* Vol 50 pp 280–313 (June 1993)

278 Stepney, S, Barden, R and Cooper, D (eds) *Object Orientation in Z*, Workshops in Computing, Springer-Verlag (1992)

This is a collection of papers describing various OOZ approaches—Hall, ZERO, MooZ, Object-Z, OOZE, Schuman & Pitt, Z++, ZEST and Fresco (an object-oriented VDM method)—in the main written by the methods' inventors, and all specifying the same two examples. The collection is a revised and expanded version of a ZIP report distributed at the 1991 Z User Meeting at York.

279 Stepney, S, Barden, R and Cooper, D 'A survey of object orientation in Z' *IEE/BCS Software Engineering Journal* Vol 7 No 2 pp 150–160 (March 1992)

280 Stepney, S and Lord, S P 'Formal specification of an access control system' *Software—Practice and Experience* Vol 17 No 9 pp 575–593 (September 1987)

281 Stocks, P *Applying formal methods to software testing*, PhD thesis, Department of Computer Science, University of Queensland, St Lucia 4072, Australia (1993)

282 Stocks, P and Carrington, D A 'Deriving software test cases from formal specifications' in *6th Australian Software Engineering Conference* pp 327–340 (July 1991)

283 Stocks, P and Carrington, D A 'Test template framework: a specification-based testing case study' in *Proc. International Symposium on Software Testing and Analysis (ISSTA'93)* pp 11–18 (June 1993)

Also available in a longer form as Technical Report UQCS-255, Department of Computer Science, University of Queensland.

284 Stocks, P and Carrington, D A 'Test templates: a specification-based testing framework' in *Proc. 15th International Conference on Software Engineering* pp 405–414 (May 1993)

Also available in a longer form as Technical Report UQCS-243, Department of Computer Science, University of Queensland.

285 Storey, A C and Haughton, H P 'A strategy for the production of verifiable code using the B method' in Naftalin *et al.*[213] pp 346–365

286 Sufrin, B A 'Formal methods and the design of effective user interfaces' in Harrison, M D and Monk, A F (eds) *People and computers: designing for usability* Cambridge University Press (1986)

287 Sufrin, B A 'Formal specification of a display-oriented editor' in Gehani, N and McGettrick, A D (eds) *Software specification techniques* International Computer Science Series, pp 223–267, Addison-Wesley (1986)

Originally published in *Science of Computer Programming* Vol 1 pp 157–202 (1982)

288 Sufrin, B A 'Effective industrial application of formal methods' in Ritter, G X (ed) *Information Processing 89, Proc. 11th IFIP Computer Congress* pp 61–69, Elsevier Science Publishers (North-Holland) (1989)

This paper presents a Z model of the Unix *make* utility.

289 Sufrin, B A and Jifeng, He 'Specification, analysis and refinement of interactive processes' in Harrison, M D and Thimbleby, H (eds) *Formal methods in human-computer interaction* Vol 2 of *Cambridge Series on Human-Computer Interaction*, Chapter 6, pp 153–200. Cambridge University Press (1990)

A case study on using Z for process modelling.

290 Swatman, P A 'Using formal specification in the acquisition of information systems: educating information systems professionals' in Bowen and Nicholls[44] pp 205–239

291 Swatman, P A, Fowler, D and Gan, C Y M 'Extending the useful application domain for formal methods' in Nicholls[226] pp 125–144

292 Till, D (ed) *6th Refinement Workshop*, Workshops in Computing, Springer-Verlag (1994)

The workshop was held at City University, London, UK, 5–7 January 1994. See[109,177].

293 Till, D and Potter, B F 'The specification in Z of gateway functions within a communications network' in *Proc. IFIP WG10.3 Conference on Distributed Processing* Elsevier Science Publishers (North-Holland) (October 1987)

294 Took, R 'The presenter–a formal design for an autonomous display manager' in Sommerville, I (ed) *Software Engineering Environments* pp 151–169, Peter Peregrinus, London (1986)

295 Toyn, I and McDermid, J A 'CADiZ: an architecture for Z tools and its implementation'. Technical document, Computer Science Department, University of York, York YO1 5DD, UK (November 1993)

296 Valentine, S H 'Z--, an executable subset of Z' in Nicholls[226] pp 157–187

297 Valentine, S H 'Putting numbers into the mathematical toolkit' in Bowen and Nicholls[44] pp 9–36

298 van Diepen, M J and van Hee, K M 'A formal semantics for Z and the link between Z and the relational algebra' in Bjørner *et al.*[27] pp 526–551

299 van Hee, K M, Somers, L J and Voorhoeve, M 'Z and high level Petri nets' in Prehn and Toetenel[242] pp 204–219

300 West, M M and Eaglestone, B M 'Software development: two approaches to animation of Z specifications using Prolog' *IEE/BCS Software Engineering Journal* Vol 7 No 4 pp 264–276 (July 1992)

301 Wezeman, C and Judge, A 'Z for managed objects' in Bowen and Hall[38] pp 108–119

302 Whitty, R W 'Structural metrics for Z specifications' in Nicholls[222] pp 186–191

303 Whysall, P J and McDermid, J A 'An approach to object-oriented specification using Z' in Nicholls[224] pp 193–215

304 Whysall, P J and McDermid, J A 'Object-oriented specification and refinement' in Morris and Shaw[212] pp 151–184

305 Wing, J M 'A specifier's introduction to formal methods' *IEEE Computer* Vol 23 No 9 pp 8–24 (September 1990)

306 Wing, J M and Zaremski, A M 'Unintrusive ways to integrate formal specifications in practice', in Prehn and Toetenel[242] pp 545–570

307 Wood, K R 'The elusive software refinery: a case study in program development' in Morris and Shaw[212] pp 281–325

308 Wood, K R 'A practical approach to software engineering using Z and the refinement calculus'

ACM Software Engineering Notes Vol 18 No 5 pp 79–88 (December 1993)

309 Woodcock, J C P 'Calculating properties of Z specifications' *ACM SIGSOFT Software Engineering Notes* Vol 14 No 4 pp 43–54 (1989)

310 Woodcock, J C P 'Mathematics as a management tool: proof rules for promotion' in *Proc. 6th Annual CSR Conference on Large Software Systems* Bristol, UK (September 1989)

311 Woodcock, J C P 'Structuring specifications in Z' *IEE/BCS Software Engineering Journal* Vol 4 No 1 pp 51–66 (January 1989)

312 Woodcock, J C P 'Implementing promoted operations in Z' in Morris and Shaw[212] pp 366–378

313 Woodcock, J C P 'A tutorial on the refinement calculus' in Prehn and Toetenel[243] pp 79–140. Vol 2: Tutorials

314 Woodcock, J C P and Brien, S M 'W: a logic for Z' in Nicholls[226] pp 77–96

315 Woodcock, J C P, Gardiner, P H B and Hulance, J R 'The formal specification in Z of Defence Standard 00-56' in Bowen and Hall[38] pp 9–28

316 Woodcock, J C P and Larsen, P G (eds) *FME'93: Industrial-strength Formal Methods* Vol 670 of *Lecture Notes in Computer Science*, Springer-Verlag (1993)

The 1st FME Symposium was held at Odense, Denmark, 19–23 April 1993. Z-related papers include[45,72,107,154,193,240].

317 Woodcock, J C P and Loomes, M *Software engineering mathematics: formal methods demystified* Pitman (1988)

318 Woodcock, J C P and Morgan, C C 'Refinement of state-based concurrent systems' in Bjørner *et al.*[27] pp 340–351.

Work on combining Z and CSP.

319 Worden, R 'Fermenting and distilling' in Bowen and Hall[38] pp 1–6

320 Wordsworth, J B 'The CICS application programming interface definition' in Nicholls[224] pp 285–294

321 Wordsworth, J B *Software development with Z* Addison-Wesley (1992)

This book provides a guide to developing software from specification to code, and is based in part on work done at IBM's UK Laboratory that won the UK Queen's Award for Technological Achievement in 1992.

Contents: Introduction; A simple Z specification; Sets and predicates; Relations and functions; Schemas and specifications; Data design; Algorithm design; Specification of an oil terminal control system.

322 Xiaoping Jia, *ZTC: a type checker for Z—user's guide* Institute for Software Engineering, Department of Computer Science and Information Systems, DePaul University, Chicago, IL 60604, USA (1994)

ZTC is a type checker for the Z specification language. ZTC accepts two forms of input: LaTeX with zed style option and ZSL, an ASCII version of Z. TC can also perform translations between the two input forms. This document is intended to serve as both a user's guide and a reference manual for TC.

323 Zave, P and Jackson, M 'Techniques for partial specification and specification of switching systems' in Prehn and Toetenel[242] pp 511–525

Also published as[324].

324 Zave, P and Jackson, M 'Techniques for partial specification and specification of switching systems' in Nicholls[226] pp 205–219

325 Zhang, Y and Hitchcock, P 'EMS: case study in methodology for designing knowledge-based systems and information systems' *Information and Software Technology* Vol 33 No 7 pp 518–526 (September 1991)